

# Appendix F-3

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Geotechnical: Fragility Curve Data

Puyallup River Basin  
Flood Risk Reduction Feasibility Study



Department of the Army  
Seattle District, US Army Corps of Engineers

# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Lindsay Cross Section Model & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Carbon River
<b>Levee Segment Name:</b>	Lindsay
<b>Station:</b>	87+60

#### Levee Condition Factor

Levee Condition Factor	1
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**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Vegetation maintenance issues and encroachments were noted.

#### Levee Geometry

Levee Geometry	
R	
W	
L	
H	
Crown Width (W)	12 Feet
Landward Levee Height (H)	9 Feet
Riverward Slope (R)	1.5 H:1V
Landward Slope (L)	2 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	9 Feet
Breach Width at Top of Levee	202 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.75 Hours*
*SERRI Report 70015-001	

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is a medium dense poorly graded SAND with silt (SP-SM).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
Loose / Soft		Low
Medium		Medium
X Dense / Stiff	X	High

**Remarks:** Levee embankment material is a dense poorly graded GRAVEL with silt and sand (GP-GM).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
116.00	1.00
116.00	0.35
113.00	0.12
110.00	0.03
107.00	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

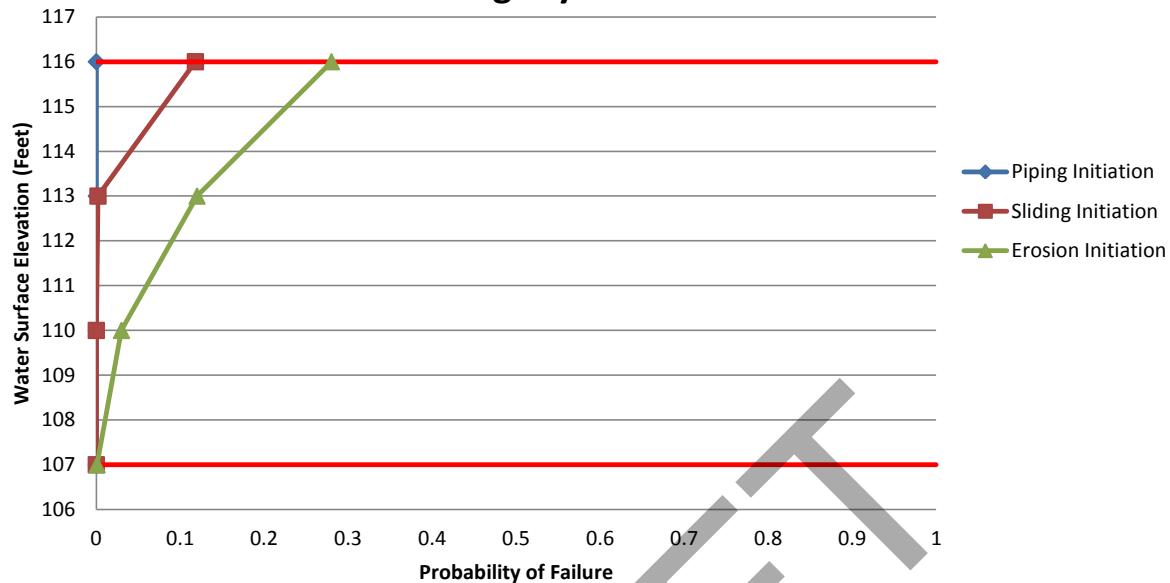
Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

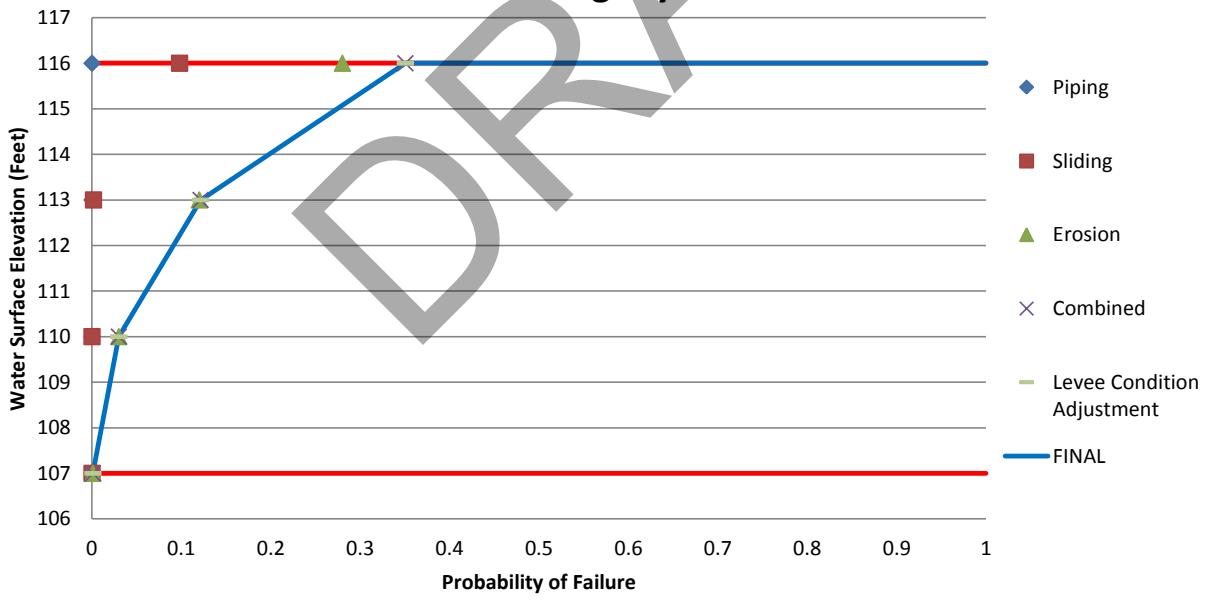
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Lindsay Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# Lindsay Levee - Carbon & Puyallup River



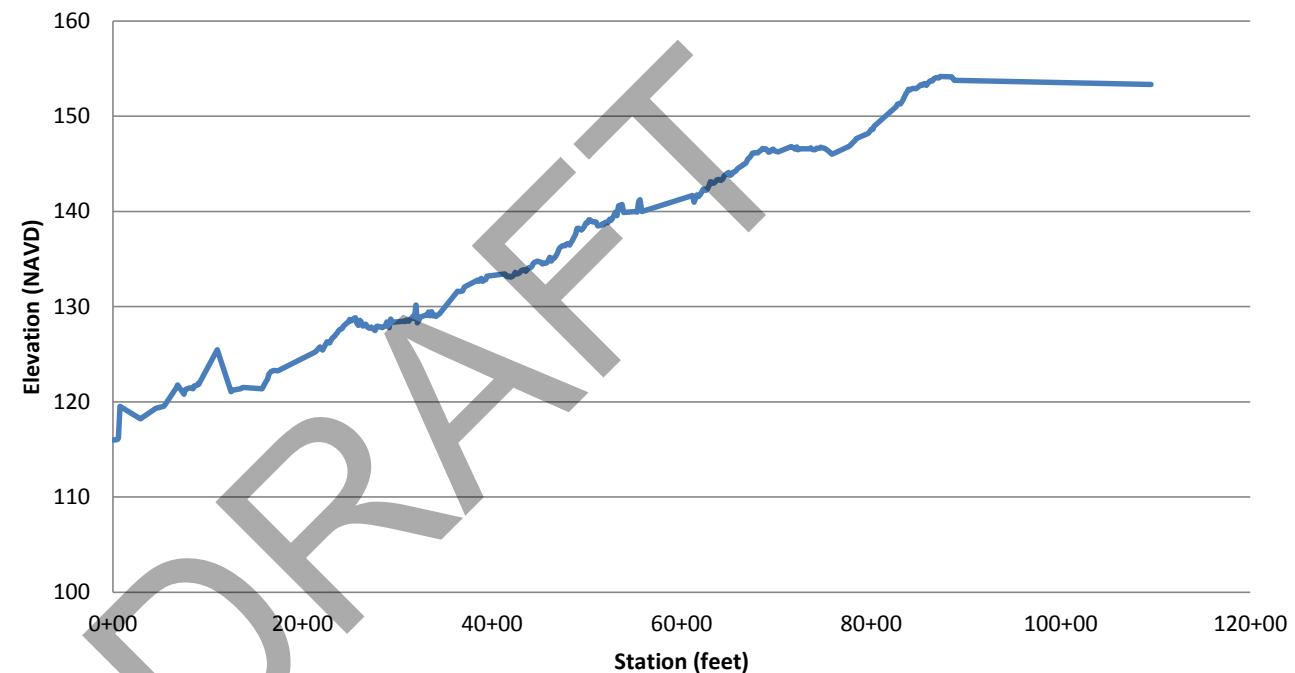
## *Lindsay Levee*

### *Carbon River*

<b>Min</b>	116.00
<b>Max</b>	154.18

<b>Station Begin</b>	0+00
<b>Station End</b>	109+53

### **Levee Profile**



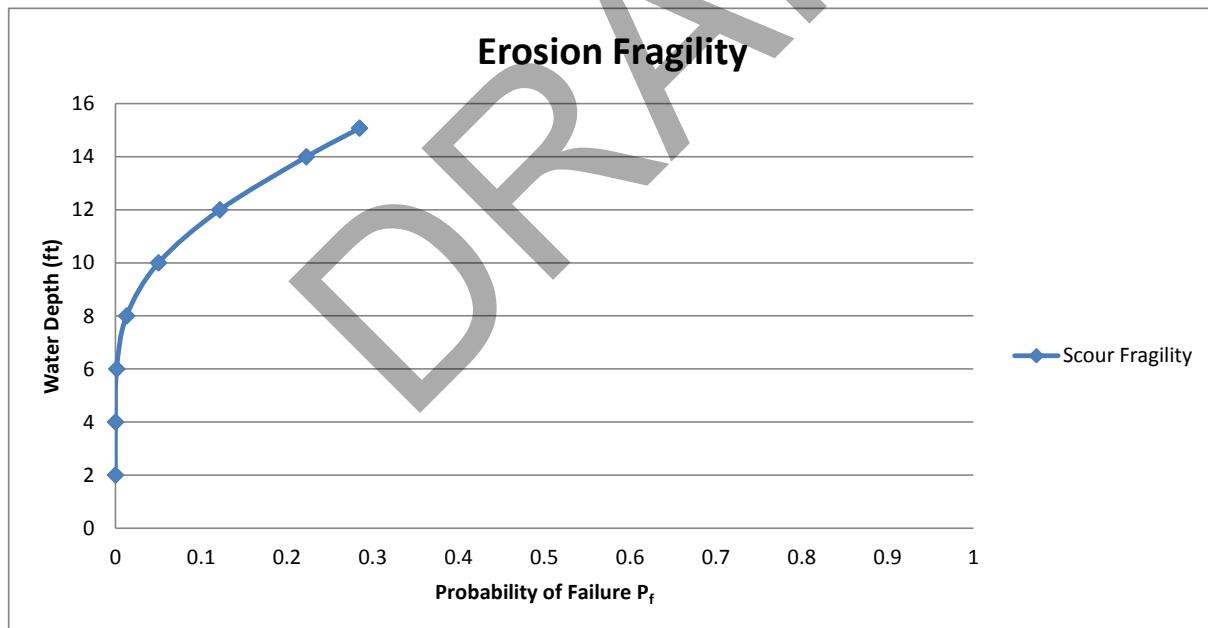
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Lindsay Levee

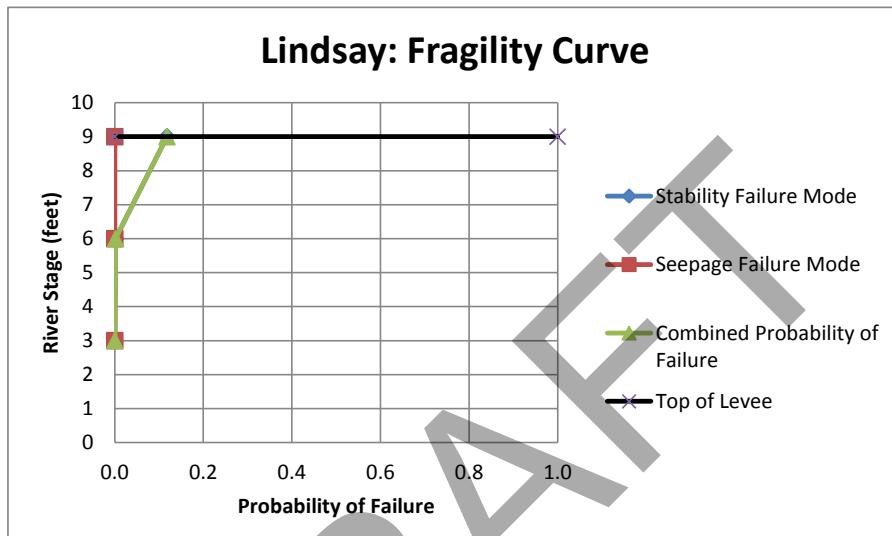
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0046	CV(s) =	0.1	0.00046
Manning's "n"	n =	0.05	CV(n) =	0.15	0.0075
Scouring Velocity		V <sub>crit</sub> =	14.23		2.85
CV(v <sub>crit</sub> )			0.2		

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	3.200	0.1581139		-1.492036725	0.254950976	-5.85225	2.4248E-09
4	5.079	0.1581139		-1.029938605	0.254950976	-4.03975	2.6754E-05
6	6.656	0.1581139		-0.759628533	0.254950976	-2.97951	0.00144356
8	8.063	0.1581139		-0.567840485	0.254950976	-2.22725	0.01296516
10	9.356	0.1581139		-0.419078117	0.254950976	-1.64376	0.05011293
12	10.565	0.1581139		-0.297530413	0.254950976	-1.16701	0.12160311
14	11.709	0.1581139		-0.194763293	0.254950976	-0.76392	0.22245612
15.08	12.303	0.1581139		-0.145221937	0.254950976	-0.56961	0.28447204



Lindsay					
Fragility Curve					
Cross Section from STA 87+60					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 9' +					
9	0.118	9	8.3E-11	9	0.118
6	0.002	6	2.6E-14	6	0.002
3	2.6E-06	3	0.0E+00	3	0.000



OVERTOPPING - 9' +	
Top of Levee	
9	0
9	1

Soil Unit	Stability	TOL		TOL - 3'		TOL - 6'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	1.19	0.32	1.38	0.21	1.51	0.10	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.20	0.32	1.38	0.21	1.51	0.10	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.18	0.32	1.38	0.21	1.51	0.10	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	log(K <sub>h</sub> )-1SD	1.19	0.32	1.38	0.21	1.51	0.10	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	1.15	0.32	1.36	0.21	1.51	0.10	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	$\gamma$ -1SD	1.18	0.28	1.38	0.18	1.51	0.09	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	$\gamma$ +1SD	1.20	0.35	1.38	0.23	1.51	0.11	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	$\phi$ -1SD	1.10	0.31	1.28	0.21	1.40	0.10	log(K <sub>h</sub> )-1SD
2	$\phi$ +1SD	1.28	0.35	1.49	0.22	1.63	0.11	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.21	0.35	1.39	0.22	1.52	0.11	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.18	0.41	1.37	0.30	1.51	0.15	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	1.15	(i)	1.36	(i)	1.51	(i)	
	log(K <sub>h</sub> )+1SD	0.90		1.18		1.43		
	$\gamma$ -1SD	1.17		1.36		1.49		
	$\gamma$ +1SD	1.20		1.40		1.53		
	$\gamma$ -1SD	1.15		1.33		1.46		
	$\gamma$ +1SD	1.23		1.43		1.57		

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Lindsay
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Lindsay Levee cross section from STA 87+60. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-3.3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-1.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	2.91	
2	52.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	2.66	
3	62.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	3.16	0.51
4	57.6	1	1.5	-3.3	-1.3	0	0	0	0	0	2.90	
5	57.6	2	1.5	-3.3	-1.3	0	0	0	0	0	2.91	0.011
6	57.6	1.5	1	-3.3	-1.3	0	0	0	0	0	3.32	
7	57.6	1.5	2	-3.3	-1.3	0	0	0	0	0	2.66	-0.66298
8	57.6	1.5	1.5	-4.3	-1.3	0	0	0	0	0	2.94	
9	57.6	1.5	1.5	-2.3	-1.3	0	0	0	0	0	2.67	-0.2668
10	57.6	1.5	1.5	-3.3	-2.3	0	0	0	0	0	2.67	
11	57.6	1.5	1.5	-3.3	-0.3	0	0	0	0	0	2.26	-0.41127
12	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		

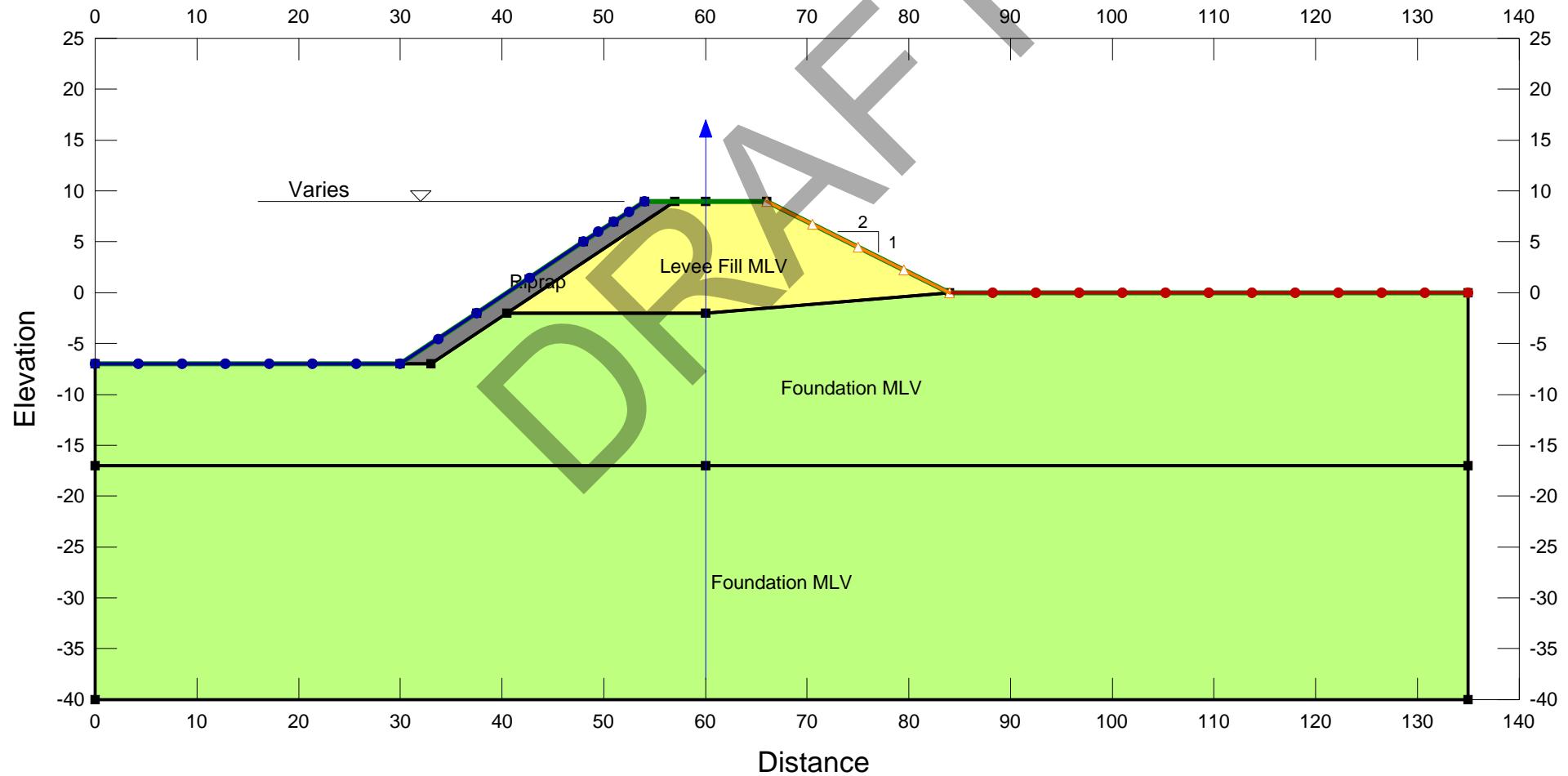
Standard deviation of F,	$\sigma_F$	0.484
Coefficient of variation of F,	$V_F$	0.166
Log normal reliability index,	$\beta_{LN}$	6.390
Reliability		1.000
Probability of failure		8.3E-11

Lindsay Levee  
Carbon River  
STA 87+60

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

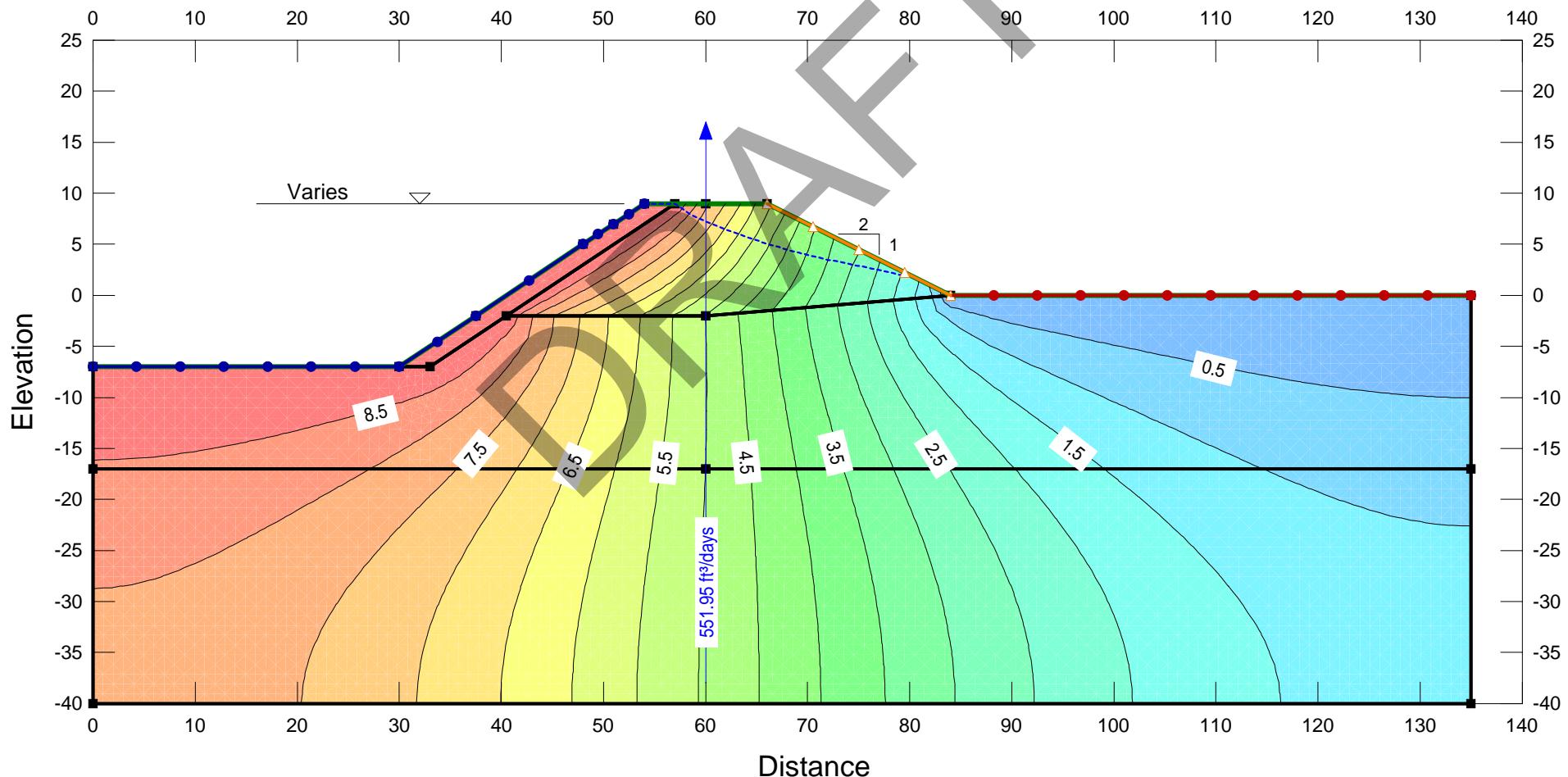


Lindsay Levee  
Carbon River  
STA 46+23

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
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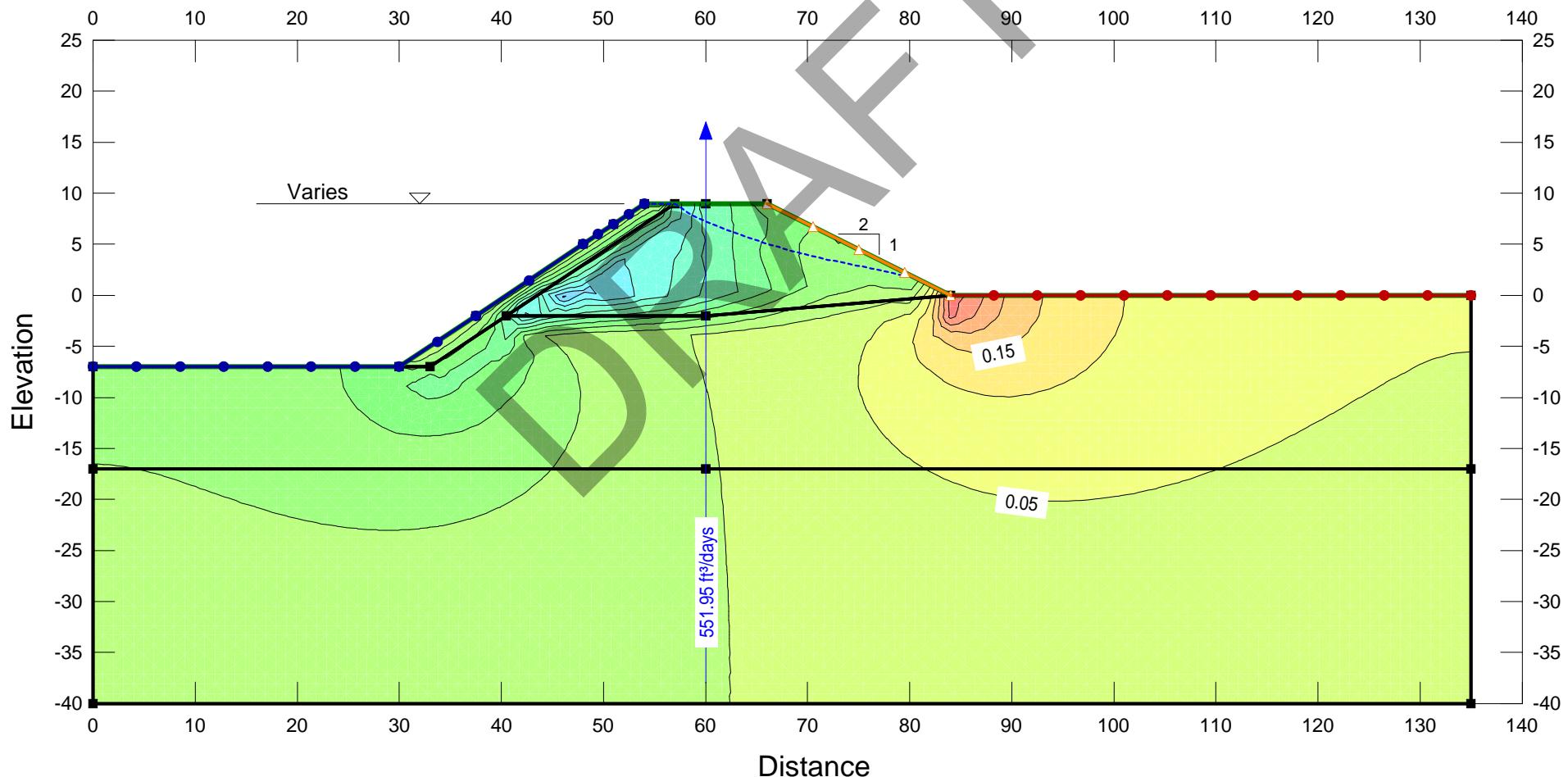


Lindsay Levee  
Carbon River  
STA 46+23

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
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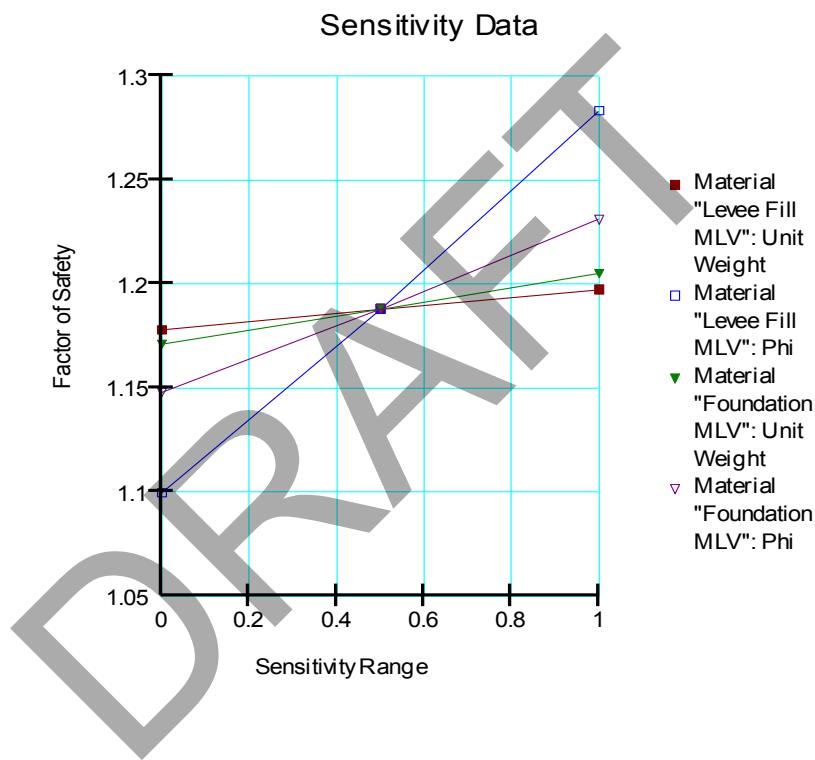
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Lindsay
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Lindsay Levee cross section from STA 87+60. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	35	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0	1.19	
2	1	-3.3	125	35	1.5	-1.3	120	33	0	0	1.20	
3	2	-3.3	125	35	1.5	-1.3	120	33	0	0	1.18	-0.02
4	1.5	-4.3	125	35	1.5	-1.3	120	33	0	0	1.19	
5	1.5	-2.3	125	35	1.5	-1.3	120	33	0	0	1.15	-0.04
6	1.5	-3.3	120	35	1.5	-1.3	120	33	0	0	1.18	
7	1.5	-3.3	130	35	1.5	-1.3	120	33	0	0	1.20	0.01933
8	1.5	-3.3	125	32	1.5	-1.3	120	33	0	0	1.10	
9	1.5	-3.3	125	38	1.5	-1.3	120	33	0	0	1.28	0.1837
10	1.5	-3.3	125	35	1	-1.3	120	33	0	0	1.21	
11	1.5	-3.3	125	35	2	-1.3	120	33	0	0	1.18	-0.03
12	1.5	-3.3	125	35	1.5	-2.3	120	33	0	0	1.15	
13	1.5	-3.3	125	35	1.5	-0.3	120	33	0	0	0.90	-0.25
14	1.5	-3.3	125	35	1.5	-1.3	115	33	0	0	1.17	
15	1.5	-3.3	125	35	1.5	-1.3	125	33	0	0	1.20	0.03399
16	1.5	-3.3	125	35	1.5	-1.3	120	30	0	0	1.15	
17	1.5	-3.3	125	35	1.5	-1.3	120	36	0	0	1.23	0.08287
18	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		
19	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		0
20	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		
21	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.164
Coefficient of variation of F,	$V_F$	0.138
Log normal reliability index,	$\beta_{LN}$	1.186
Reliability		0.882
Probability of failure		0.118

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.1779825	1.0997345	1.1709903	1.1480354
0.5	1.1880402	1.1880402	1.1880402	1.1880402
1	1.197316	1.2834328	1.204984	1.2309037

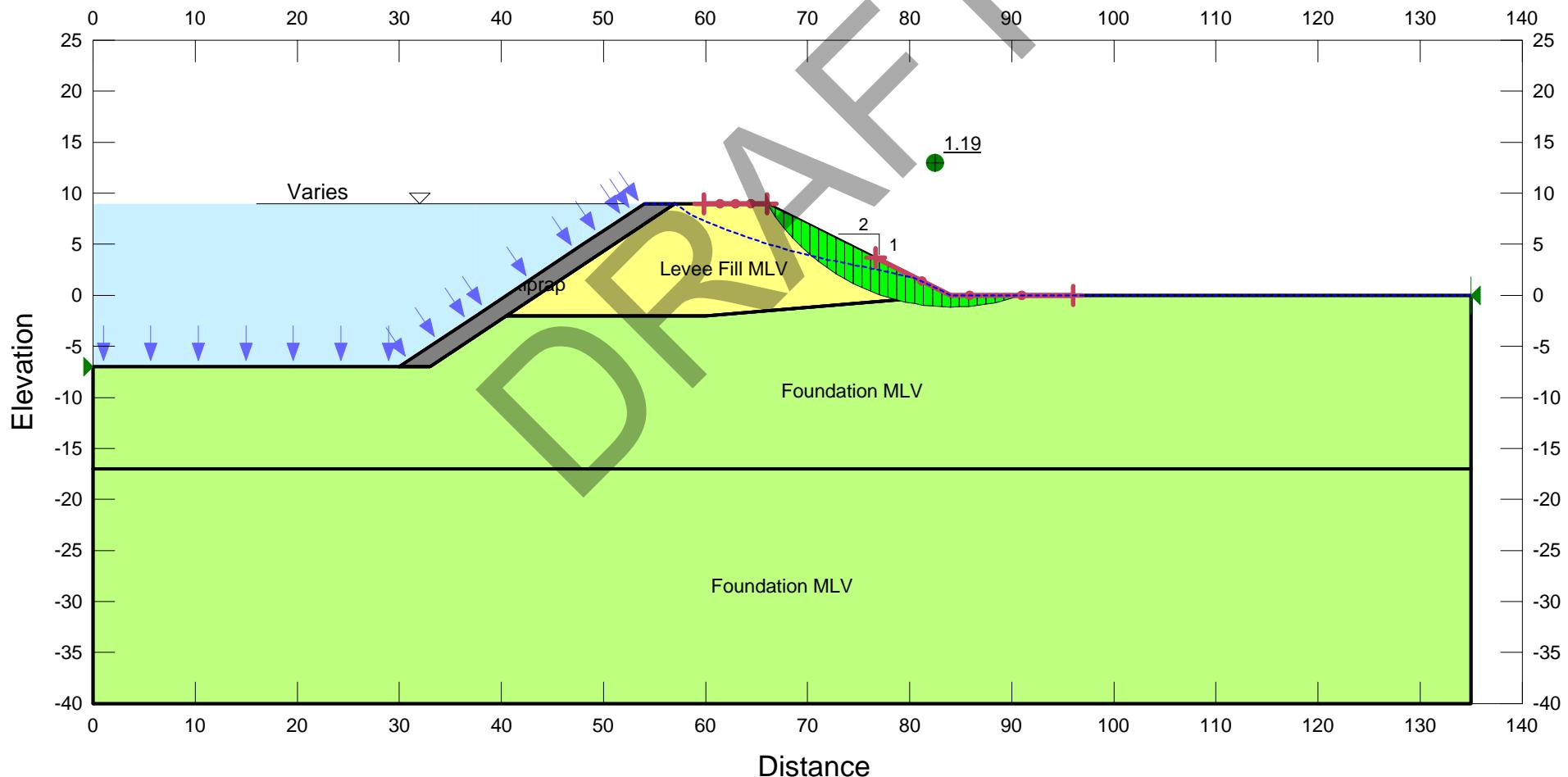


Lindsay Levee  
Carbon River  
STA 87+60

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Lindsay
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Lindsay Levee cross section from STA 87+60. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3.3	cm/s	1
5	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	4.43	
2	52.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	4.04	
3	62.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	4.81	0.76862
4	57.6	1	1.5	-3.3	-1.3	0	0	0	0	0	4.42	
5	57.6	2	1.5	-3.3	-1.3	0	0	0	0	0	4.43	0.00849
6	57.6	1.5	1	-3.3	-1.3	0	0	0	0	0	5.07	
7	57.6	1.5	2	-3.3	-1.3	0	0	0	0	0	4.02	-1.05045
8	57.6	1.5	1.5	-4.3	-1.3	0	0	0	0	0	4.45	
9	57.6	1.5	1.5	-2.3	-1.3	0	0	0	0	0	4.26	-0.19083
10	57.6	1.5	1.5	-3.3	-2.3	0	0	0	0	0	4.25	
11	57.6	1.5	1.5	-3.3	-0.3	0	0	0	0	0	3.11	-1.14581
12	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		

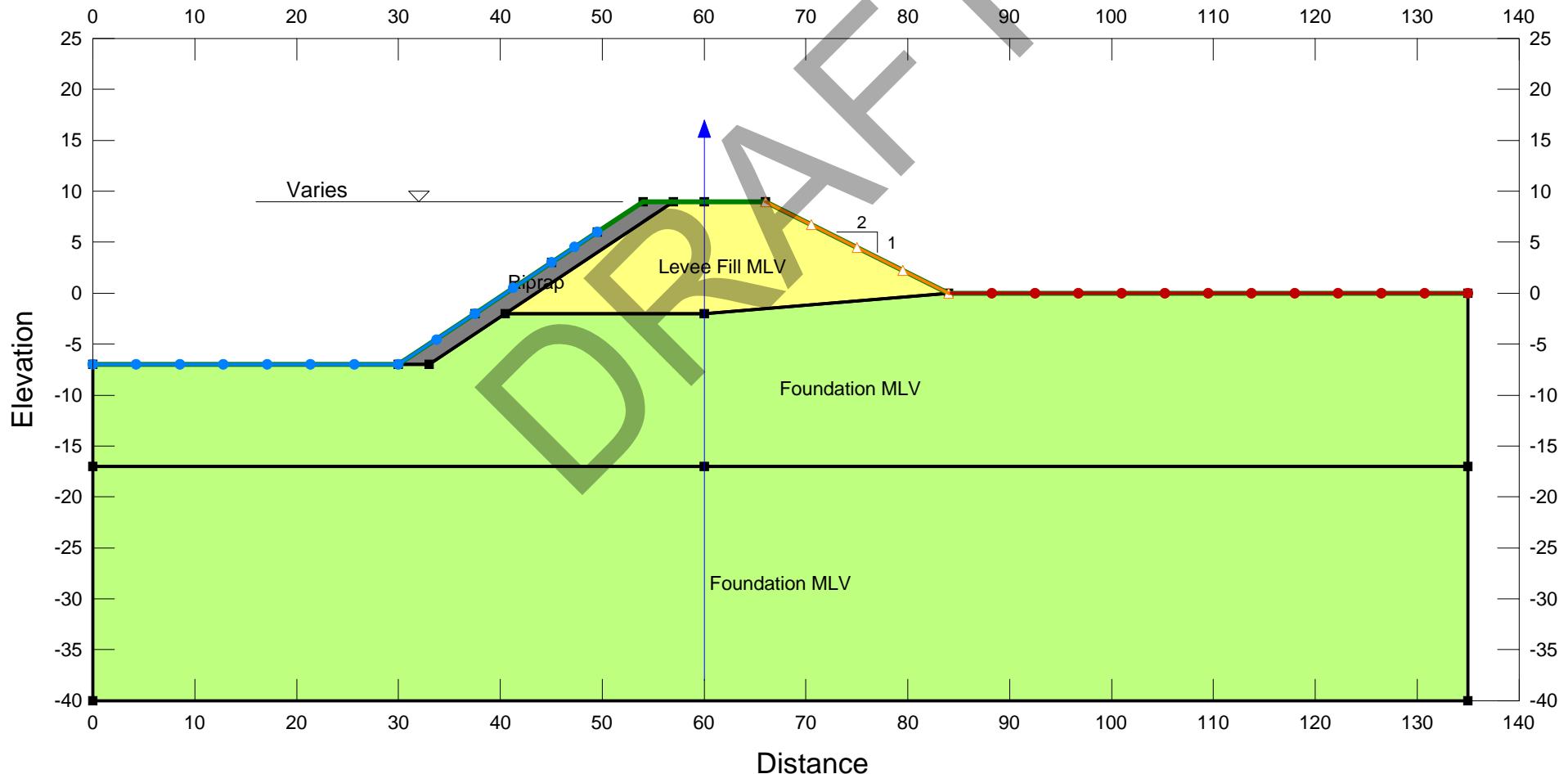
Standard deviation of F,	$\sigma_F$	0.872
Coefficient of variation of F,	$V_F$	0.197
Log normal reliability index,	$\beta_{LN}$	7.526
Reliability		1.000
Probability of failure		2.6E-14

Lindsay Levee  
Carbon River  
STA 87+60

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

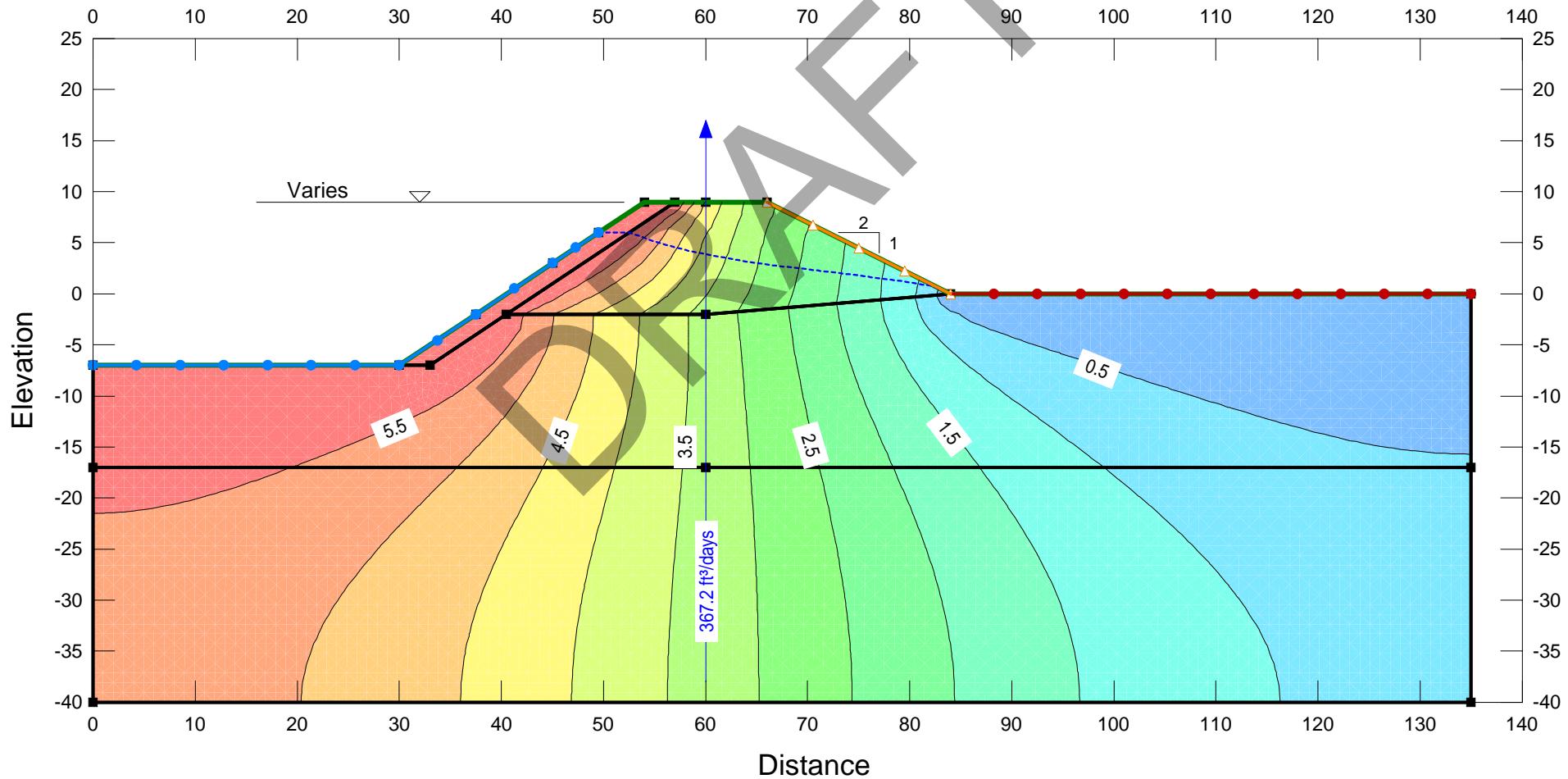


Lindsay Levee  
Carbon River  
STA 46+23

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

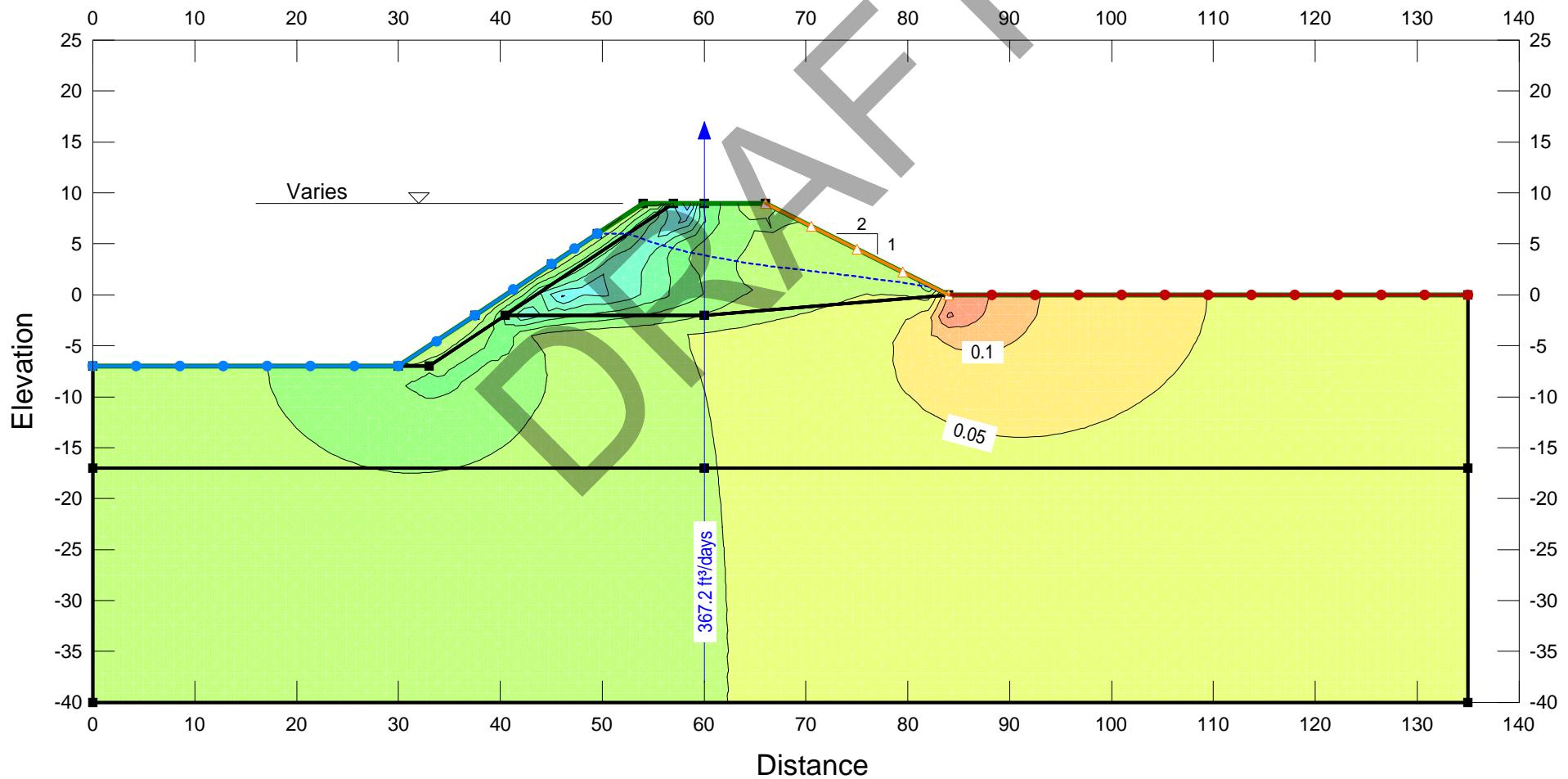


Lindsay Levee  
Carbon River  
STA 46+23

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)



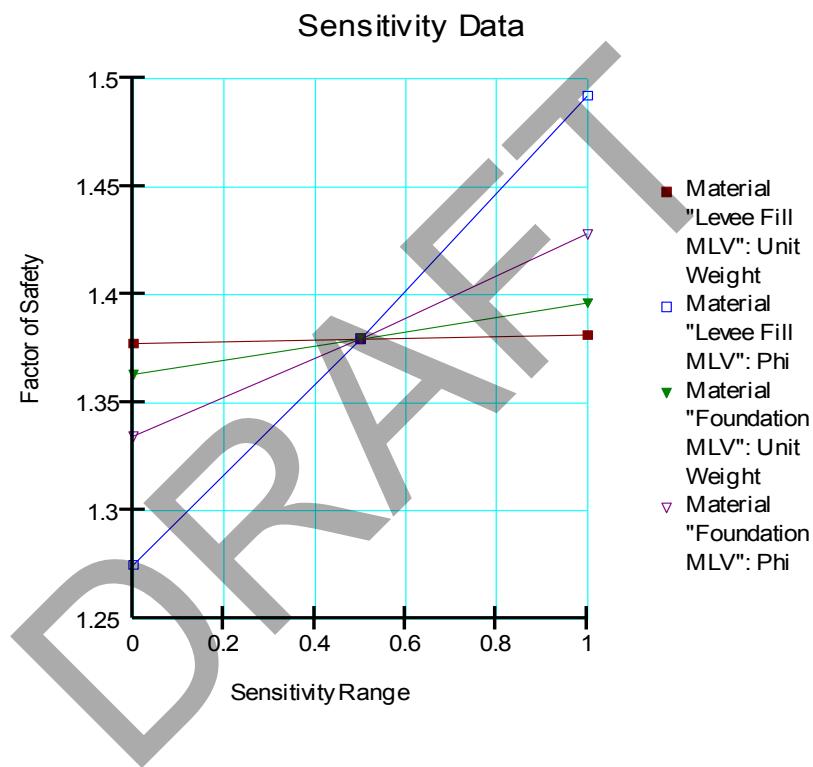
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Lindsay
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Lindsay Levee cross section from STA 87+60. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	35	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0	1.38	
2	1	-3.3	125	35	1.5	-1.3	120	33	0	0	1.38	
3	2	-3.3	125	35	1.5	-1.3	120	33	0	0	1.38	0
4	1.5	-4.3	125	35	1.5	-1.3	120	33	0	0	1.38	
5	1.5	-2.3	125	35	1.5	-1.3	120	33	0	0	1.36	-0.02
6	1.5	-3.3	120	35	1.5	-1.3	120	33	0	0	1.38	
7	1.5	-3.3	130	35	1.5	-1.3	120	33	0	0	1.38	0.00402
8	1.5	-3.3	125	32	1.5	-1.3	120	33	0	0	1.28	
9	1.5	-3.3	125	38	1.5	-1.3	120	33	0	0	1.49	0.21691
10	1.5	-3.3	125	35	1	-1.3	120	33	0	0	1.39	
11	1.5	-3.3	125	35	2	-1.3	120	33	0	0	1.37	-0.02
12	1.5	-3.3	125	35	1.5	-2.3	120	33	0	0	1.36	
13	1.5	-3.3	125	35	1.5	-0.3	120	33	0	0	1.18	-0.18
14	1.5	-3.3	125	35	1.5	-1.3	115	33	0	0	1.36	
15	1.5	-3.3	125	35	1.5	-1.3	125	33	0	0	1.40	0.033
16	1.5	-3.3	125	35	1.5	-1.3	120	30	0	0	1.33	
17	1.5	-3.3	125	35	1.5	-1.3	120	36	0	0	1.43	0.09354
18	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		
19	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		0
20	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		
21	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.150
Coefficient of variation of F,	$V_F$	0.109
Log normal reliability index,	$\beta_{LN}$	2.913
Reliability		0.998
Probability of failure		0.002

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.3775275	1.2752538	1.3630852	1.3345042
0.5	1.3796227	1.3796227	1.3796227	1.3796227
1	1.3815522	1.4921641	1.3960867	1.4280439

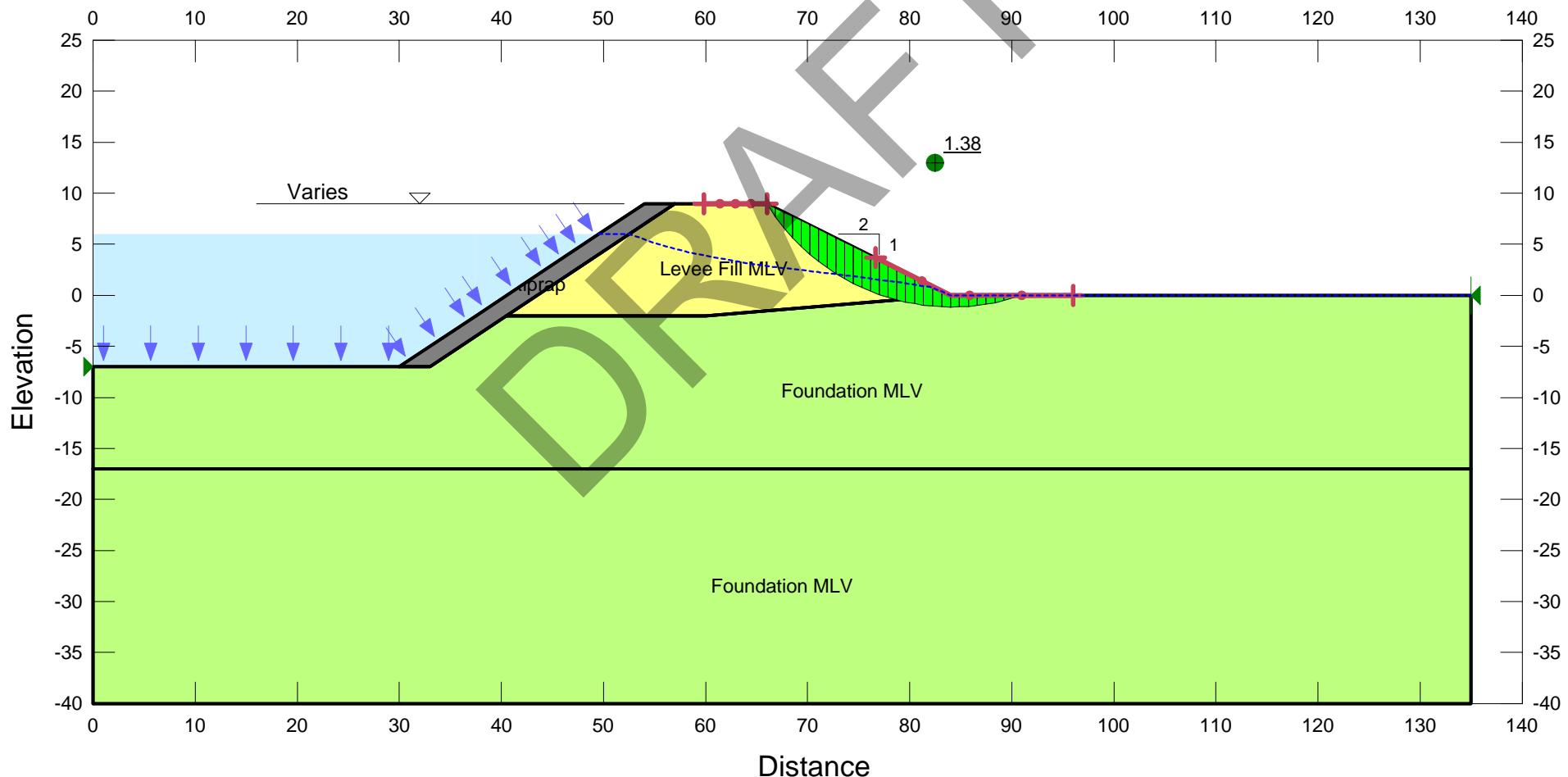


Lindsay Levee  
Carbon River  
STA 87+60

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Lindsay
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Lindsay Levee cross section from STA 87+60. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3.3	cm/s	1
5	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	8.88	
2	52.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	8.11	
3	62.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0	9.65	1.54093
4	57.6	1	1.5	-3.3	-1.3	0	0	0	0	0	8.88	
5	57.6	2	1.5	-3.3	-1.3	0	0	0	0	0	8.88	0
6	57.6	1.5	1	-3.3	-1.3	0	0	0	0	0	10.14	
7	57.6	1.5	2	-3.3	-1.3	0	0	0	0	0	8.05	-2.08893
8	57.6	1.5	1.5	-4.3	-1.3	0	0	0	0	0	8.89	
9	57.6	1.5	1.5	-2.3	-1.3	0	0	0	0	0	8.67	-0.22545
10	57.6	1.5	1.5	-3.3	-2.3	0	0	0	0	0	8.66	
11	57.6	1.5	1.5	-3.3	-0.3	0	0	0	0	0	6.03	-2.63395
12	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3.3	-1.3	0	0	0	0	0		

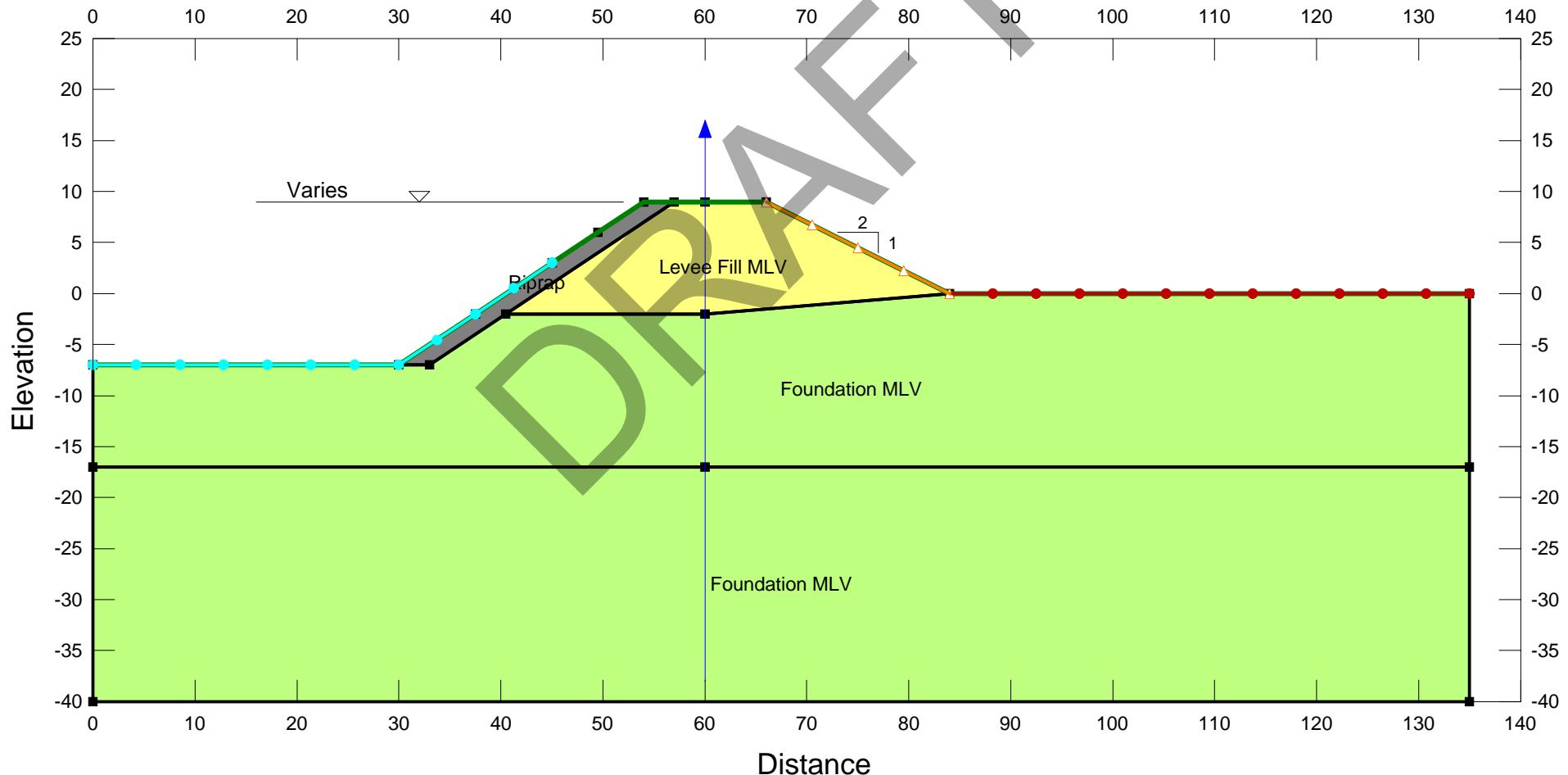
Standard deviation of F,	$\sigma_F$	1.852
Coefficient of variation of F,	$V_F$	0.209
Log normal reliability index,	$\beta_{LN}$	10.470
Reliability		1.000
Probability of failure		0.0E+00

Lindsay Levee  
Carbon River  
STA 87+60

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

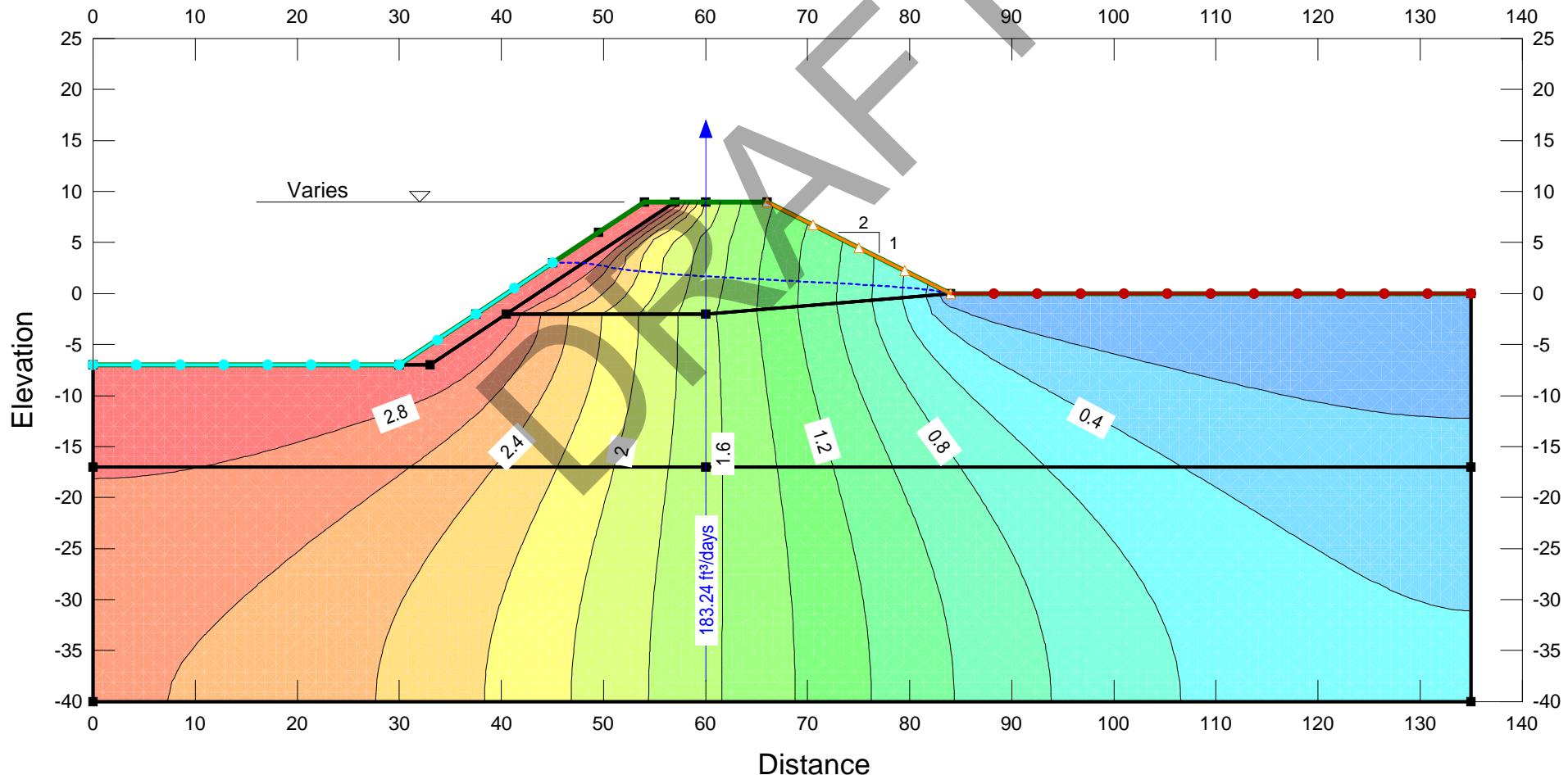


Lindsay Levee  
Carbon River  
STA 46+23

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

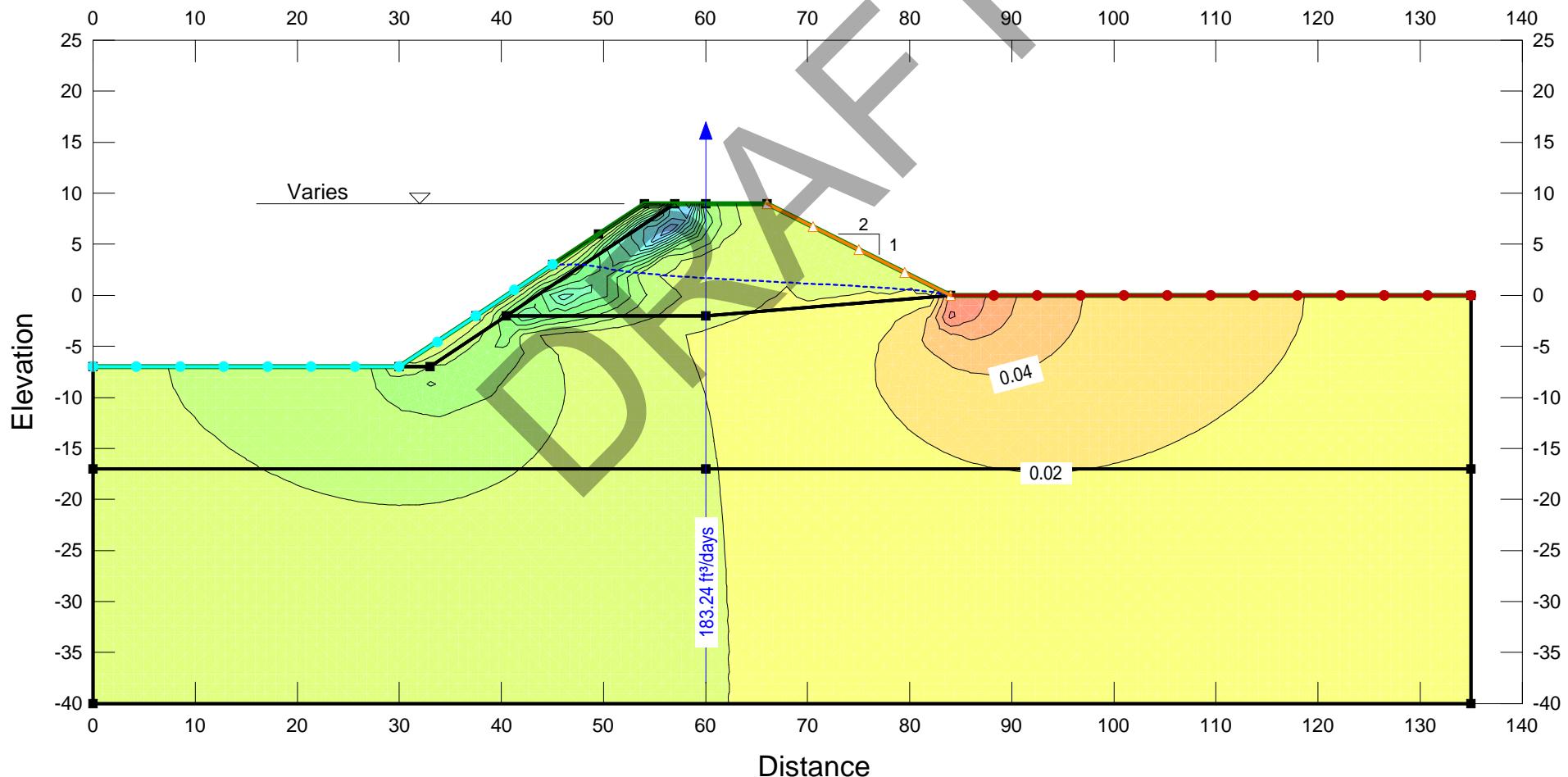


Lindsay Levee  
Carbon River  
STA 46+23

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)



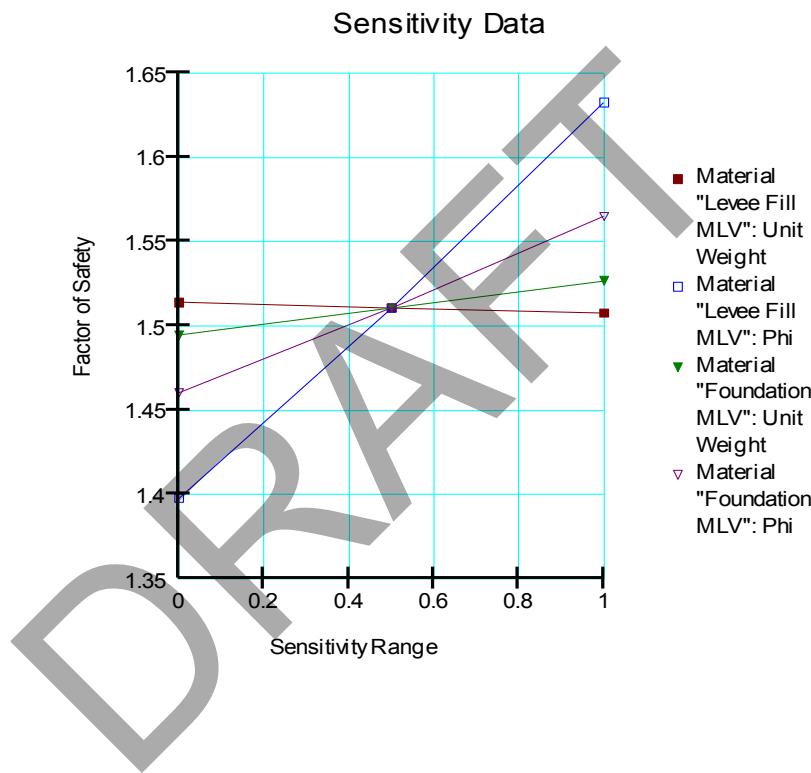
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Lindsay
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Lindsay Levee cross section from STA 87+60. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	35	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0	1.51	
2	1	-3.3	125	35	1.5	-1.3	120	33	0	0	1.51	
3	2	-3.3	125	35	1.5	-1.3	120	33	0	0	1.51	0
4	1.5	-4.3	125	35	1.5	-1.3	120	33	0	0	1.51	
5	1.5	-2.3	125	35	1.5	-1.3	120	33	0	0	1.51	0
6	1.5	-3.3	120	35	1.5	-1.3	120	33	0	0	1.51	
7	1.5	-3.3	130	35	1.5	-1.3	120	33	0	0	1.51	-0.00647
8	1.5	-3.3	125	32	1.5	-1.3	120	33	0	0	1.40	
9	1.5	-3.3	125	38	1.5	-1.3	120	33	0	0	1.63	0.23483
10	1.5	-3.3	125	35	1	-1.3	120	33	0	0	1.52	
11	1.5	-3.3	125	35	2	-1.3	120	33	0	0	1.51	-0.01
12	1.5	-3.3	125	35	1.5	-2.3	120	33	0	0	1.51	
13	1.5	-3.3	125	35	1.5	-0.3	120	33	0	0	1.43	-0.08
14	1.5	-3.3	125	35	1.5	-1.3	115	33	0	0	1.49	
15	1.5	-3.3	125	35	1.5	-1.3	125	33	0	0	1.53	0.03239
16	1.5	-3.3	125	35	1.5	-1.3	120	30	0	0	1.46	
17	1.5	-3.3	125	35	1.5	-1.3	120	36	0	0	1.57	0.10464
18	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		
19	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		0
20	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		
21	1.5	-3.3	125	35	1.5	-1.3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.136
Coefficient of variation of F,	$V_F$	0.090
Log normal reliability index,	$\beta_{LN}$	4.556
Reliability		1.000
Probability of failure		2.6E-06

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.5140479	1.3978917	1.4944588	1.460377
0.5	1.5106837	1.5106837	1.5106837	1.5106837
1	1.5075743	1.6327197	1.526853	1.5650129

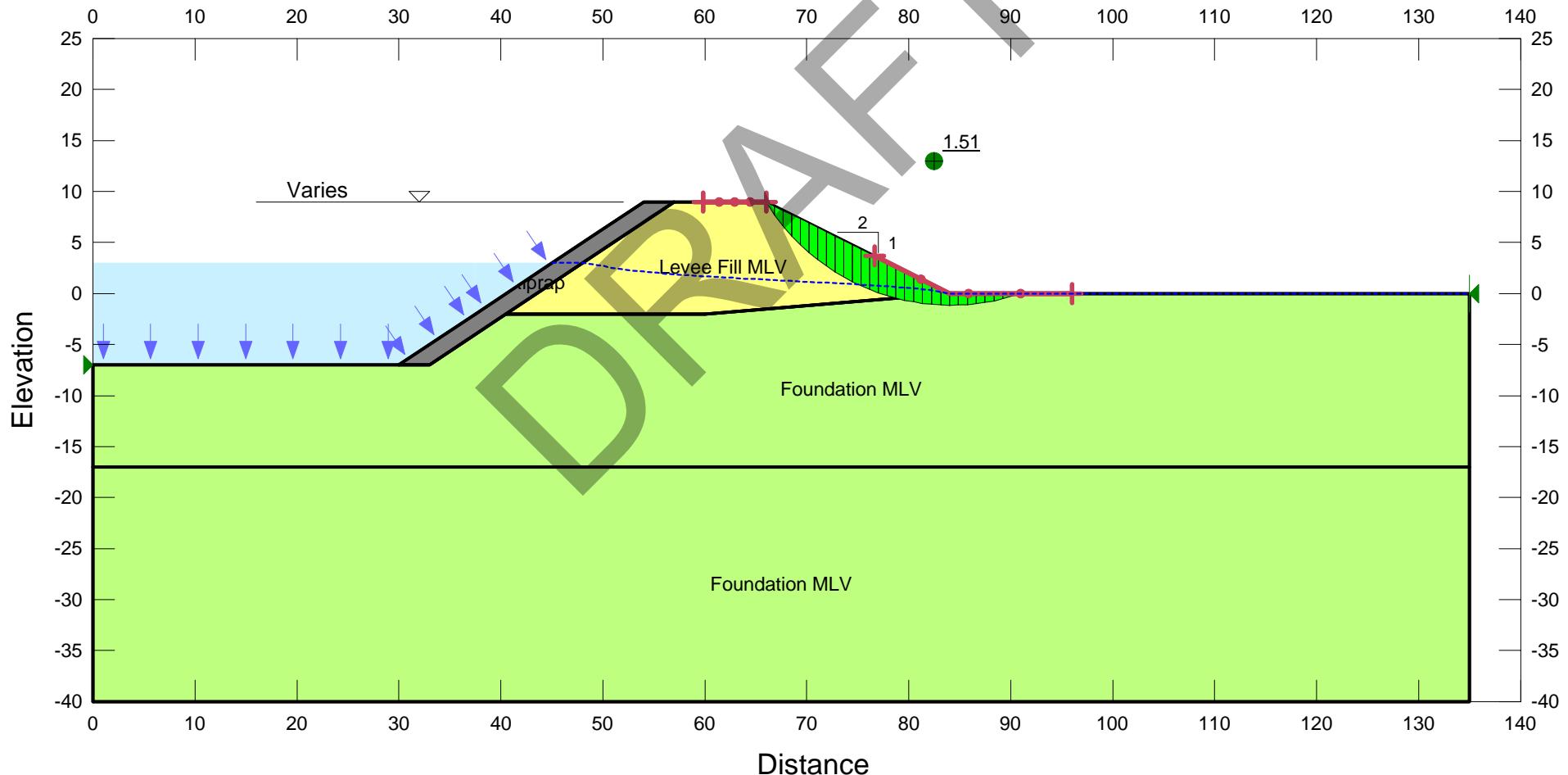


Lindsay Levee  
Carbon River  
STA 87+60

Levee Fill (GP-GM)  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 125 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP-SM)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

Location:	Pierce County, Washington
River:	Puyallup River
Levee Segment Name:	Mcabee
Station:	21+75

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Only vegetation maintenance issues were noted.

#### Levee Geometry

Crown Width (W)	30 Feet
Landward Levee Height (H)	5 Feet
Riverward Slope (R)	2.4 H:1V
Landward Slope (L)	4.8 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	5 Feet
Breach Width at Top of Levee	112 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.97 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

Homogeneous Foundation
Interbedded Foundation
Layered Foundation

**Remarks:** Levee foundation material unknown.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
Loose / Soft		Low
Medium		Medium
Dense / Stiff		High

**Remarks:** Levee embankment material unknown.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
245.80	1.00
245.80	0.33
243.80	0.22
241.80	0.10
240.80	0.06

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

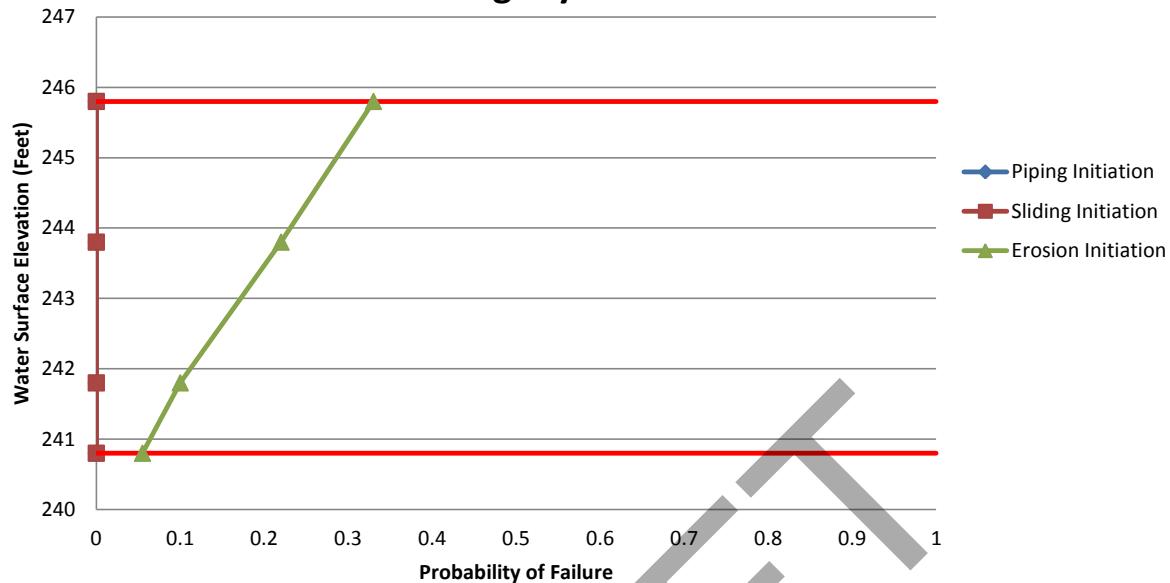
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

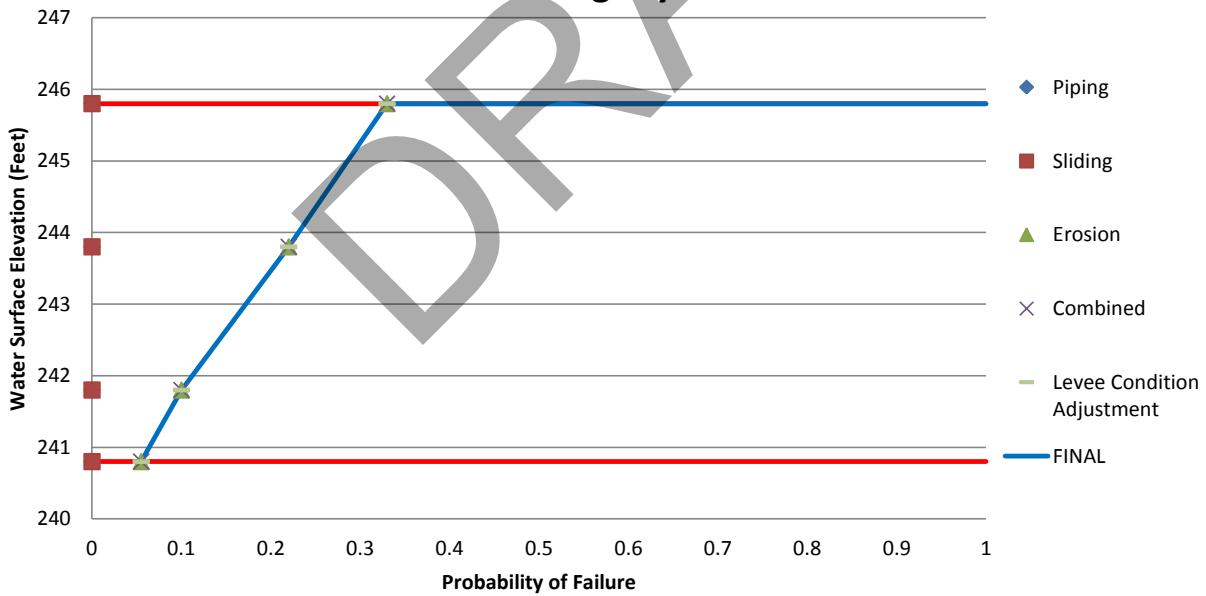
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



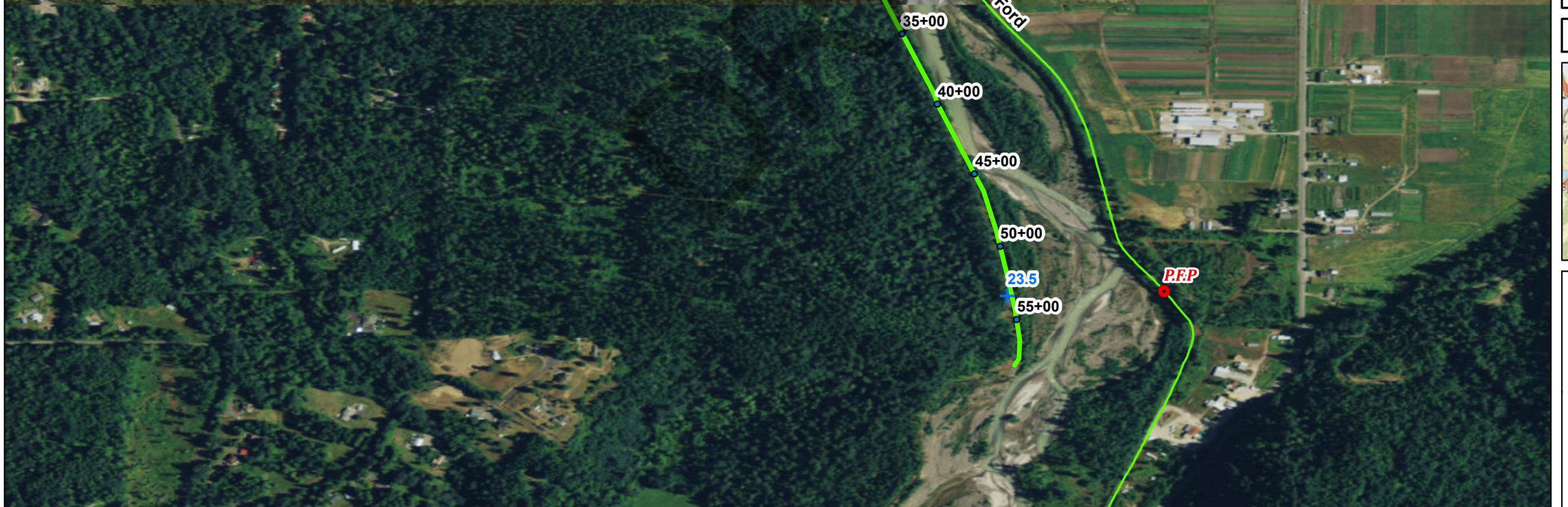
*Remarks:* The final levee fragility curve for the McAbee Levee is only accounting unique erosion computational values for probability of failure. Engineering judgment was used based on the geometry of the levee prism to conclude probability of failure for sliding and piping are essentially zero.

# McAbee Levee - Puyallup River

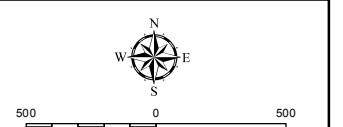
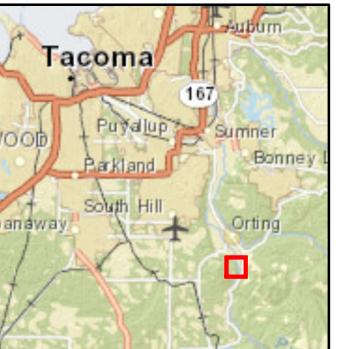


## Legend

- Potential Failure Point
- ◆ 2011 USACE Boring
- H&H Levee Breach Locations
- Levee Station
- Levee Centerline
- + River Mileposts



## Location Map



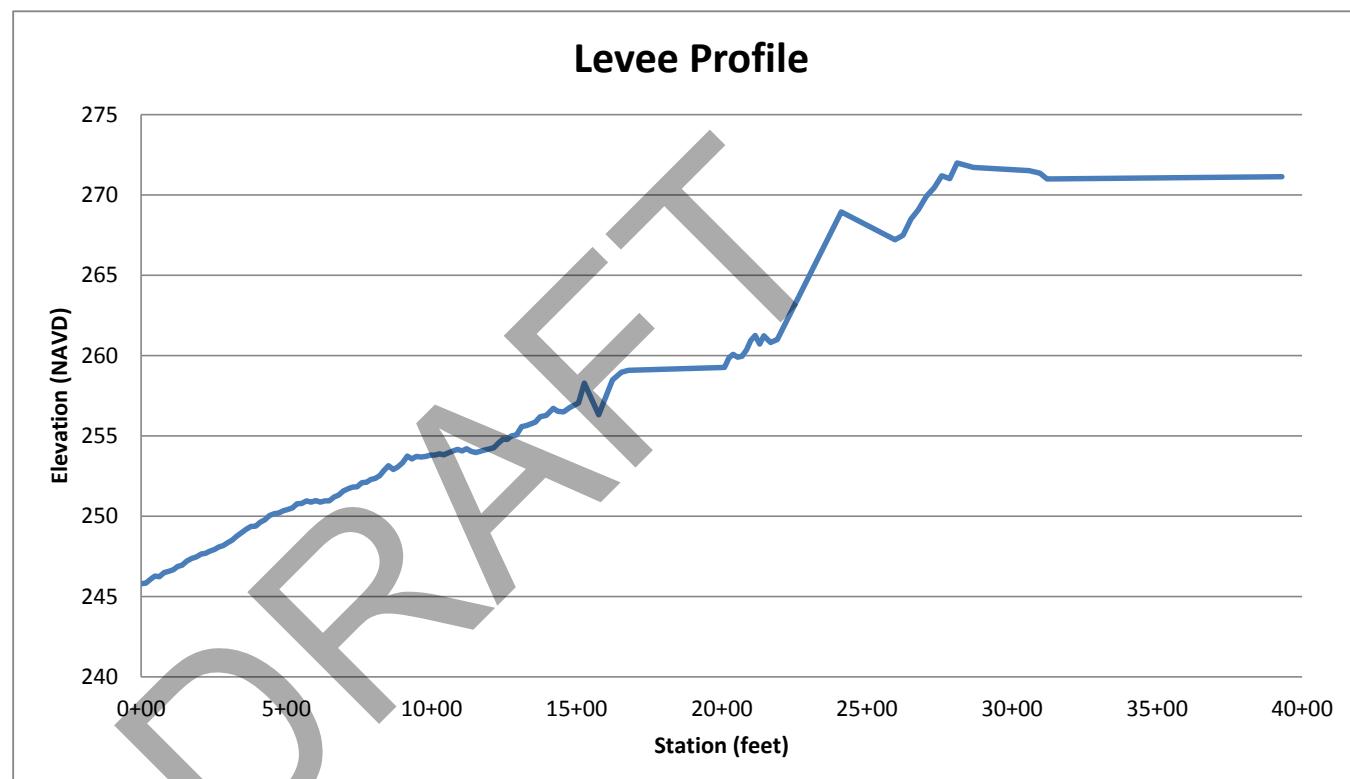
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## **McAbee Levee**

### **Puyallup River**

<b>Min</b>	245.80
<b>Max</b>	271.99

<b>Station Begin</b>	0+00
<b>Station End</b>	39+30



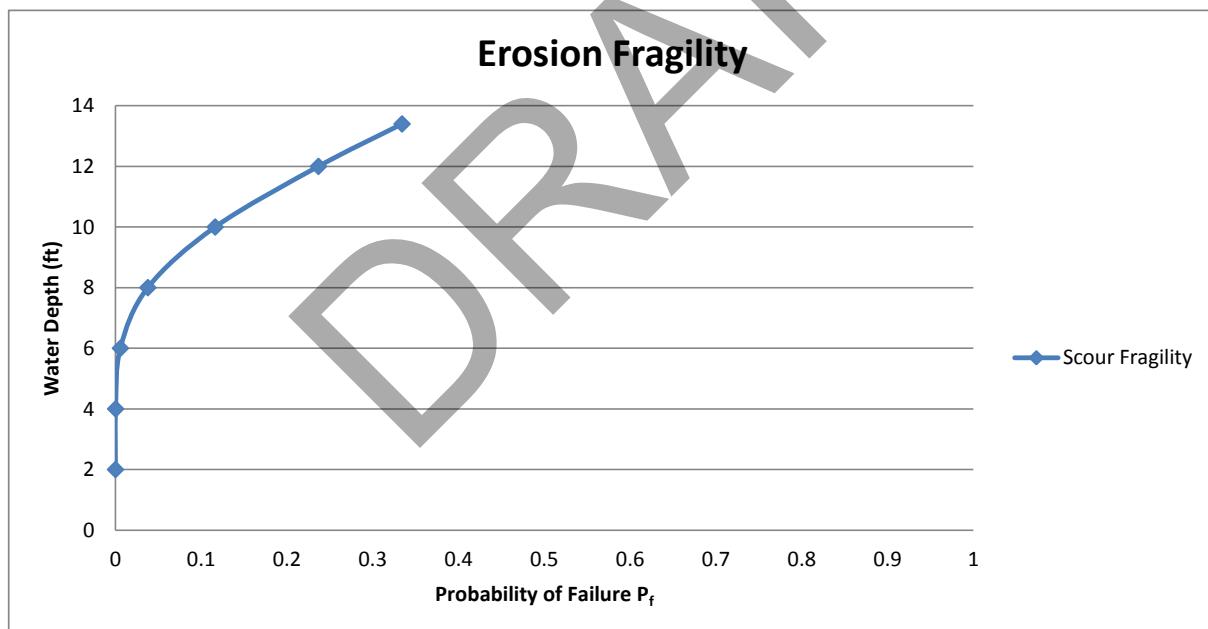
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### McAbee Levee

Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.007	CV(s) =	0.1
Manning's "n"	n =	0.055	CV(n) =	0.15
Scouring Velocity		V <sub>crit</sub> = 14.23	CV(V <sub>crit</sub> )	0.2
				2.85

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	3.588	0.1581139		-1.377419982	0.254950976	-5.40269	3.2825E-08
4	5.696	0.1581139		-0.915321862	0.254950976	-3.59019	0.00016522
6	7.464	0.1581139		-0.64501179	0.254950976	-2.52994	0.00570403
8	9.042	0.1581139		-0.453223742	0.254950976	-1.77769	0.03772741
10	10.492	0.1581139		-0.304461374	0.254950976	-1.1942	0.1162007
12	11.848	0.1581139		-0.18291367	0.254950976	-0.71745	0.23654934
13.4	12.753	0.1581139		-0.109348298	0.254950976	-0.4289	0.33399825



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

McMillin Cross Section Model & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	McMillin
<b>Station:</b>	39+25

#### Levee Condition Factor

Levee Condition Factor	2
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**Remarks:** Levee is deemed a 2 because the levee is unacceptable per USACE guidance. Vegetation maintenance issues and overtopping damage were noted.

#### Levee Geometry

Crown Width (W)	15 Feet
Landward Levee Height (H)	5 Feet
Riverward Slope (R)	2.1 H:1V
Landward Slope (L)	2 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	5 Feet
Breach Width at Top of Levee	112 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.97 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is a medium dense poorly graded SAND with gravel (SP).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )	
	Loose / Soft		Low
X	Medium	X	Medium
	Dense / Stiff		High

**Remarks:** Levee embankment material is unknown. Assumed typical values for a SAND with silt and gravel (SP-SM).

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

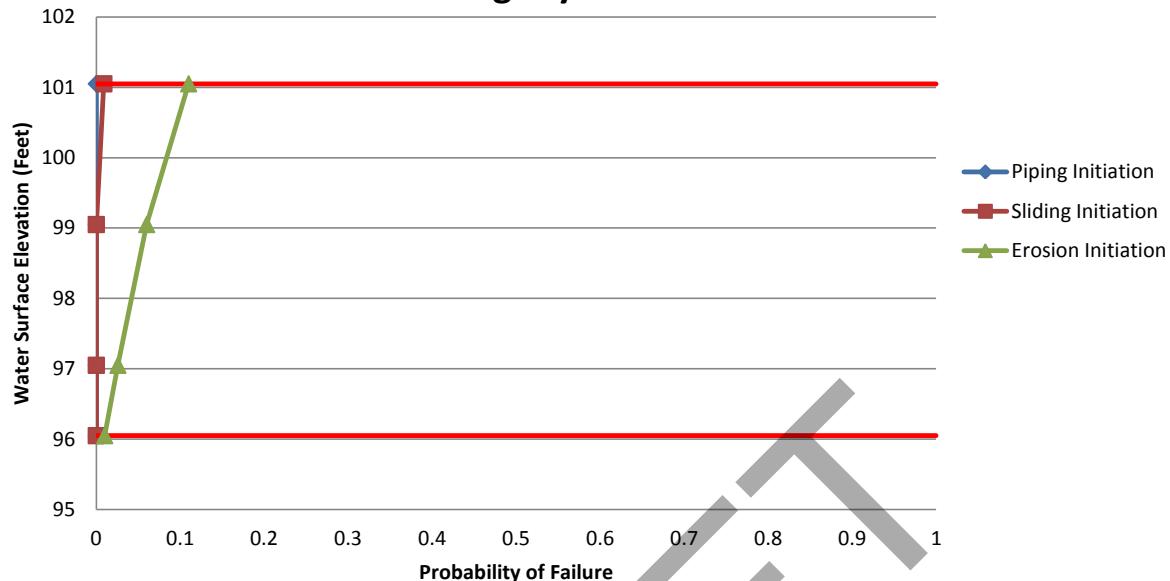
#### Final Fragility Curve

Elev.	Prob.
101.05	1.00
101.05	0.23
99.05	0.12
97.05	0.05
96.05	0.02

# PUYALLUP BASIN GENERAL INVESTIGATION

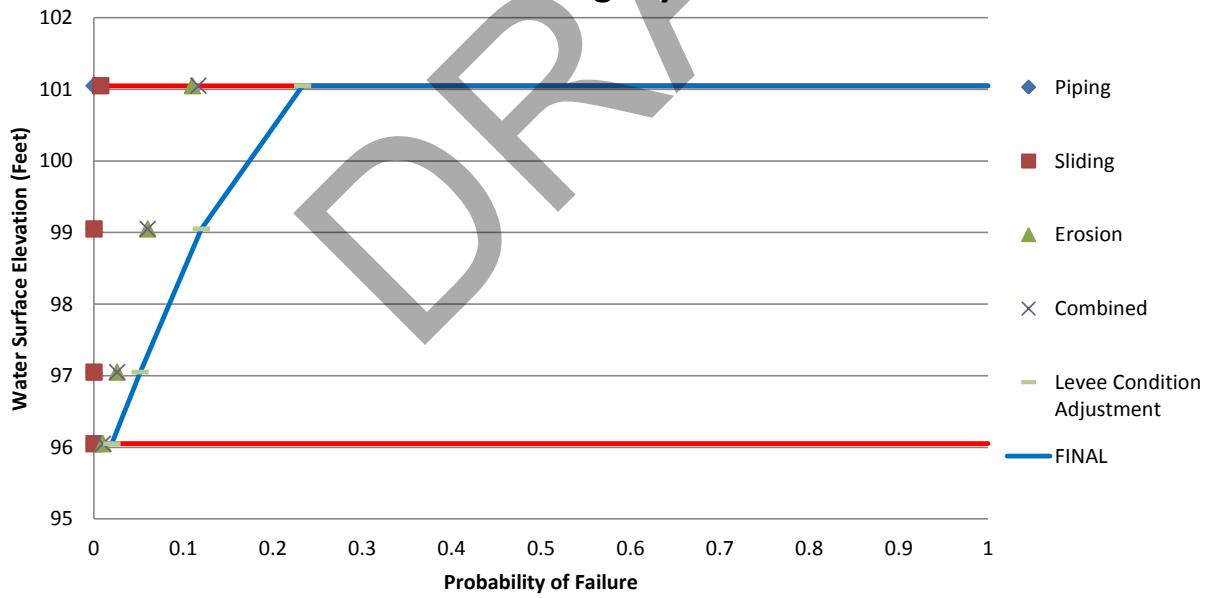
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



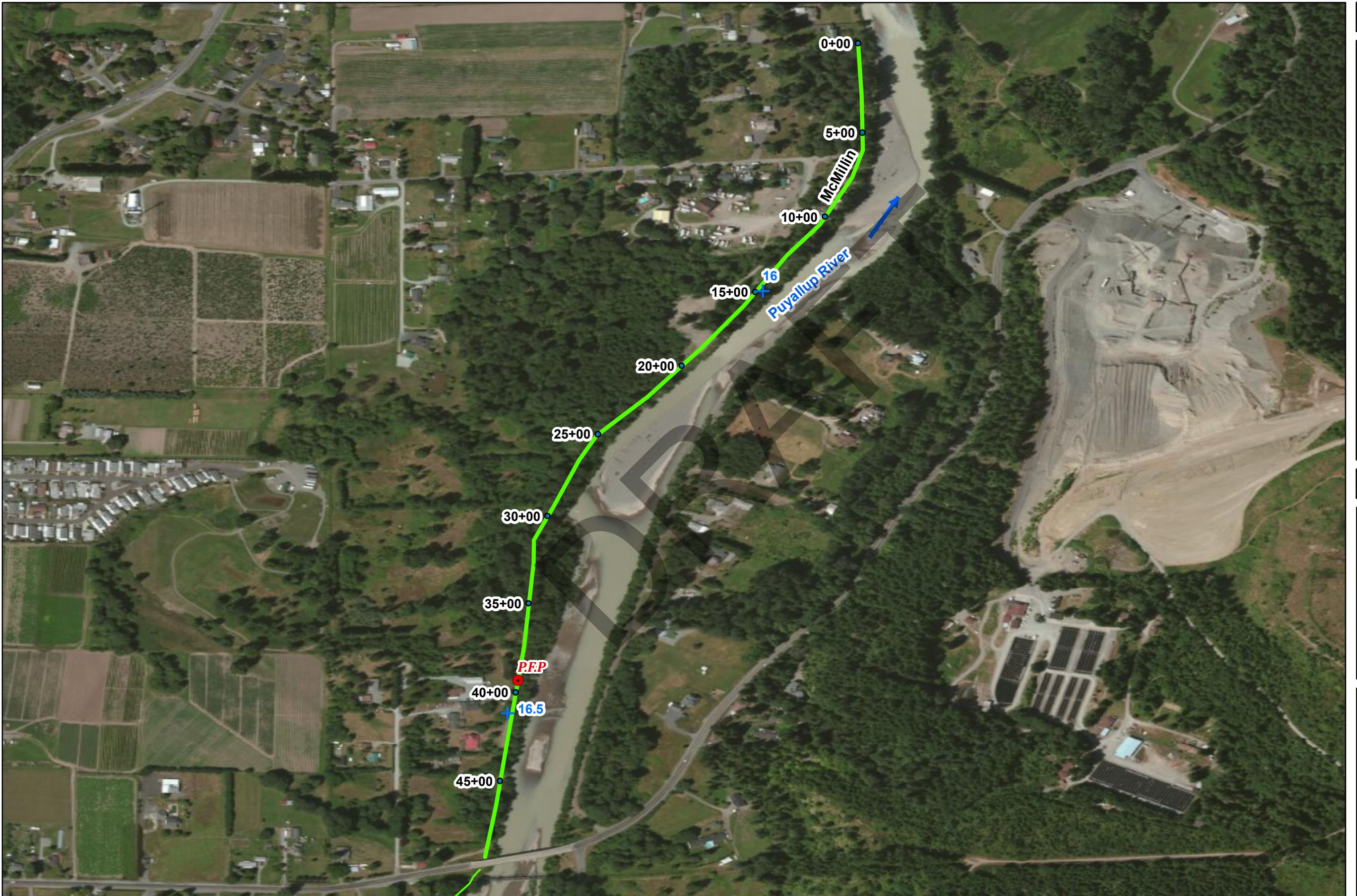
*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the McMillin Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Unacceptable levee condition was found to increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

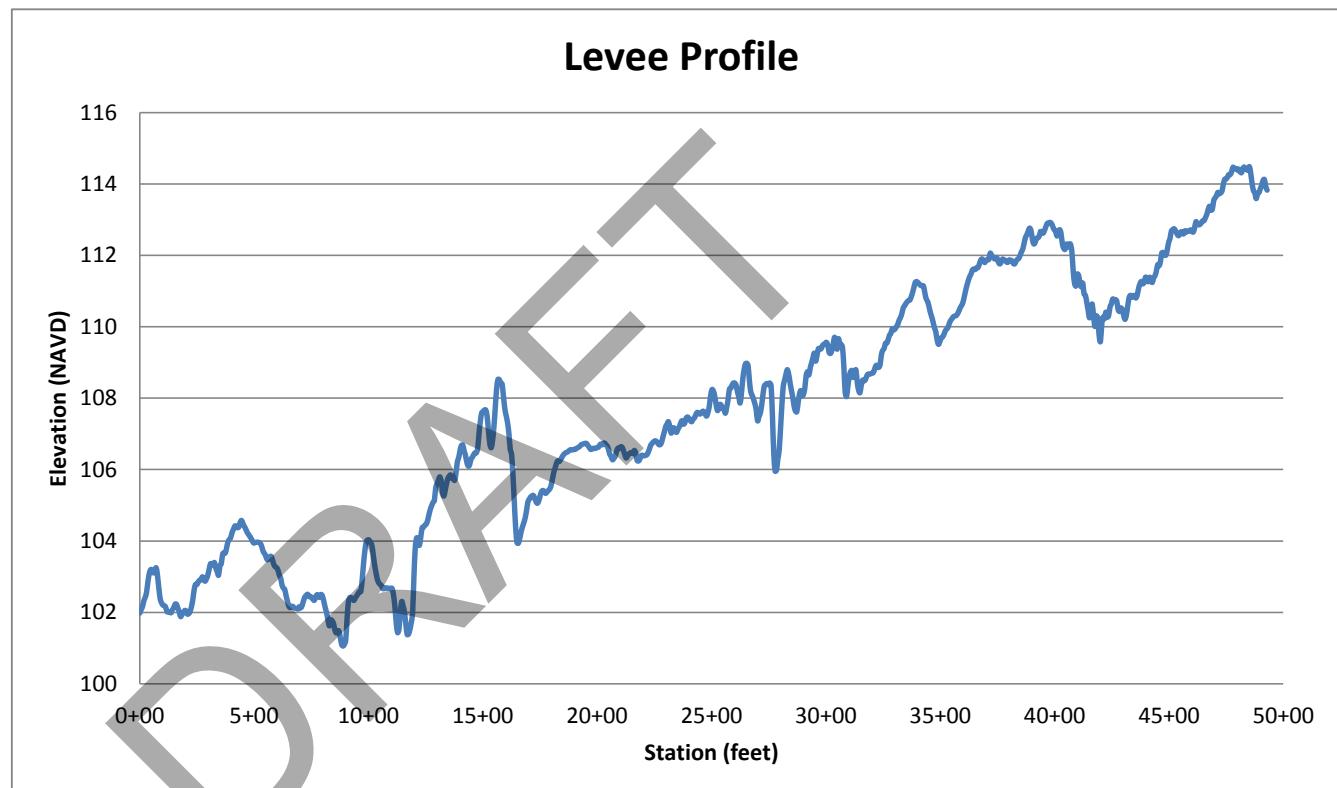
# McMillin Levee - Puyallup River



**McMillin**  
**Puyallup River**

<b>Min</b>	0.00
<b>Max</b>	114.49

<b>Station Begin</b>	0+00
<b>Station End</b>	49+30

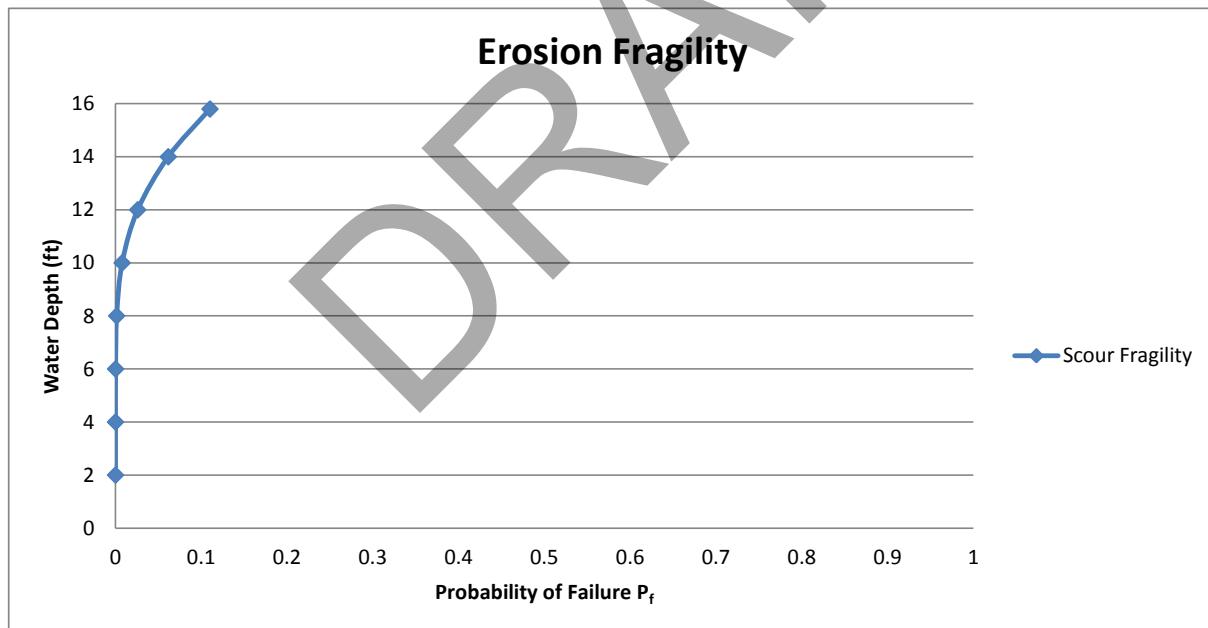


## Surface Erosion Analysis

### McMillin Levee

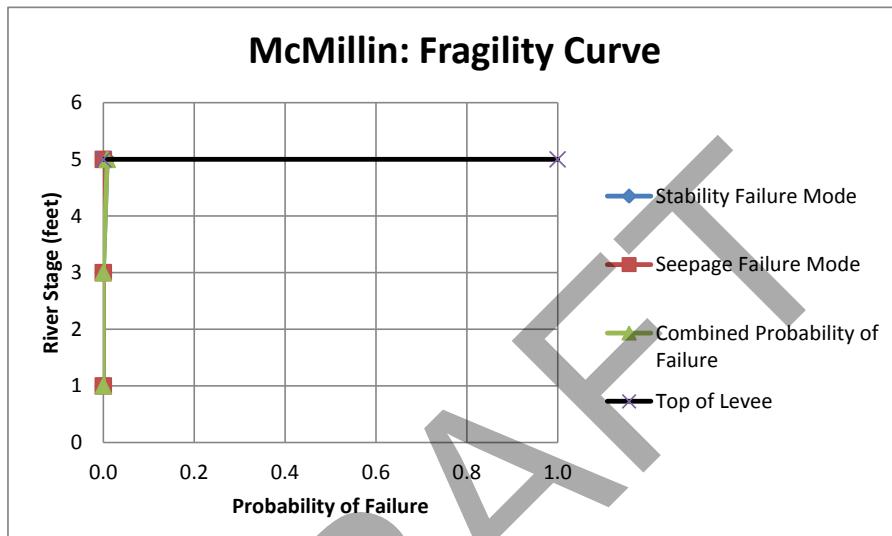
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0029	CV(s) =	0.1	0.00029
Manning's "n"	n =	0.05	CV(n) =	0.15	0.0075
Scouring Velocity		$V_{crit} =$	$13.77$		2.75
		$CV(V_{crit})$	0.2		

Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	2.541	0.1581139		-1.690440248	0.254950976	-6.63045	1.6733E-11
4	4.033	0.1581139		-1.228342128	0.254950976	-4.81795	7.2519E-07
6	5.285	0.1581139		-0.958032056	0.254950976	-3.75771	8.5737E-05
8	6.402	0.1581139		-0.766244007	0.254950976	-3.00546	0.00132591
10	7.429	0.1581139		-0.61748164	0.254950976	-2.42196	0.00771848
12	8.389	0.1581139		-0.495933935	0.254950976	-1.94521	0.02587468
14	9.297	0.1581139		-0.393166815	0.254950976	-1.54213	0.06152135
15.8	10.077	0.1581139		-0.312531742	0.254950976	-1.22585	0.1101275



McMillin					
Fragility Curve					
Cross Section from STA 39+25					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 5' +					
5	0.009	5	2.7E-05	5	0.009
3	3.4E-06	3	7.9E-10	3	0.000
1	3.3E-09	1	2.4E-08	1	0.000



OVERTOPPING - 5' +	
Top of Levee	
5	0
5	1

Soil Unit	Stability	TOL		TOL -2'		TOL -4'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	1.46	0.14	1.57	0.08	1.66	0.06	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.45	0.14	1.57	0.08	1.65	0.06	γB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.45	0.14	1.57	0.08	1.65	0.06	γB +1SD
	log(K <sub>h</sub> )-1SD	1.52	0.15	1.59	0.08	1.66	0.06	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	1.24	0.14	1.48	0.08	1.63	0.06	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	γ -1SD	1.47	0.12	1.58	0.08	1.68	0.06	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	γ +1SD	1.45	0.16	1.56	0.09	1.65	0.06	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	φ -1SD	1.39	0.11	1.50	0.06	1.58	0.08	log(K <sub>h</sub> )-1SD
2	φ +1SD	1.53	0.23	1.65	0.13	1.74	0.06	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.48	0.25	1.58	0.14	1.66	0.04	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.43	0.14	1.55	0.08	1.65	0.03	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	1.22	(i)	1.46	(i)	1.63	(i)	
	log(K <sub>h</sub> )+1SD	1.46		1.57		1.66		
	γ -1SD	1.42		1.53		1.62		
	γ +1SD	1.50		1.61		1.70		
	γ -1SD	1.36		1.47		1.55		
	γ +1SD	1.56		1.68		1.78		

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	McMillin
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	McMillin cross section from STA 39+25. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-2	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-2	0	0	0	0	0	6.55	
2	52.6	1.5	1.5	-3	-2	0	0	0	0	0	5.98	
3	62.6	1.5	1.5	-3	-2	0	0	0	0	0	7.11	1.14
4	57.6	1	1.5	-3	-2	0	0	0	0	0	6.24	
5	57.6	2	1.5	-3	-2	0	0	0	0	0	6.79	0.55032
6	57.6	1.5	1	-3	-2	0	0	0	0	0	7.81	
7	57.6	1.5	2	-3	-2	0	0	0	0	0	5.78	-2.02576
8	57.6	1.5	1.5	-4	-2	0	0	0	0	0	8.66	
9	57.6	1.5	1.5	-2	-2	0	0	0	0	0	3.98	-4.67705
10	57.6	1.5	1.5	-3	-3	0	0	0	0	0	3.70	
11	57.6	1.5	1.5	-3	-1	0	0	0	0	0	6.74	3.04152
12	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-2	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	3.034
Coefficient of variation of F,	$V_F$	0.463
Log normal reliability index,	$\beta_{LN}$	4.039
Reliability		1.000
Probability of failure		2.7E-05

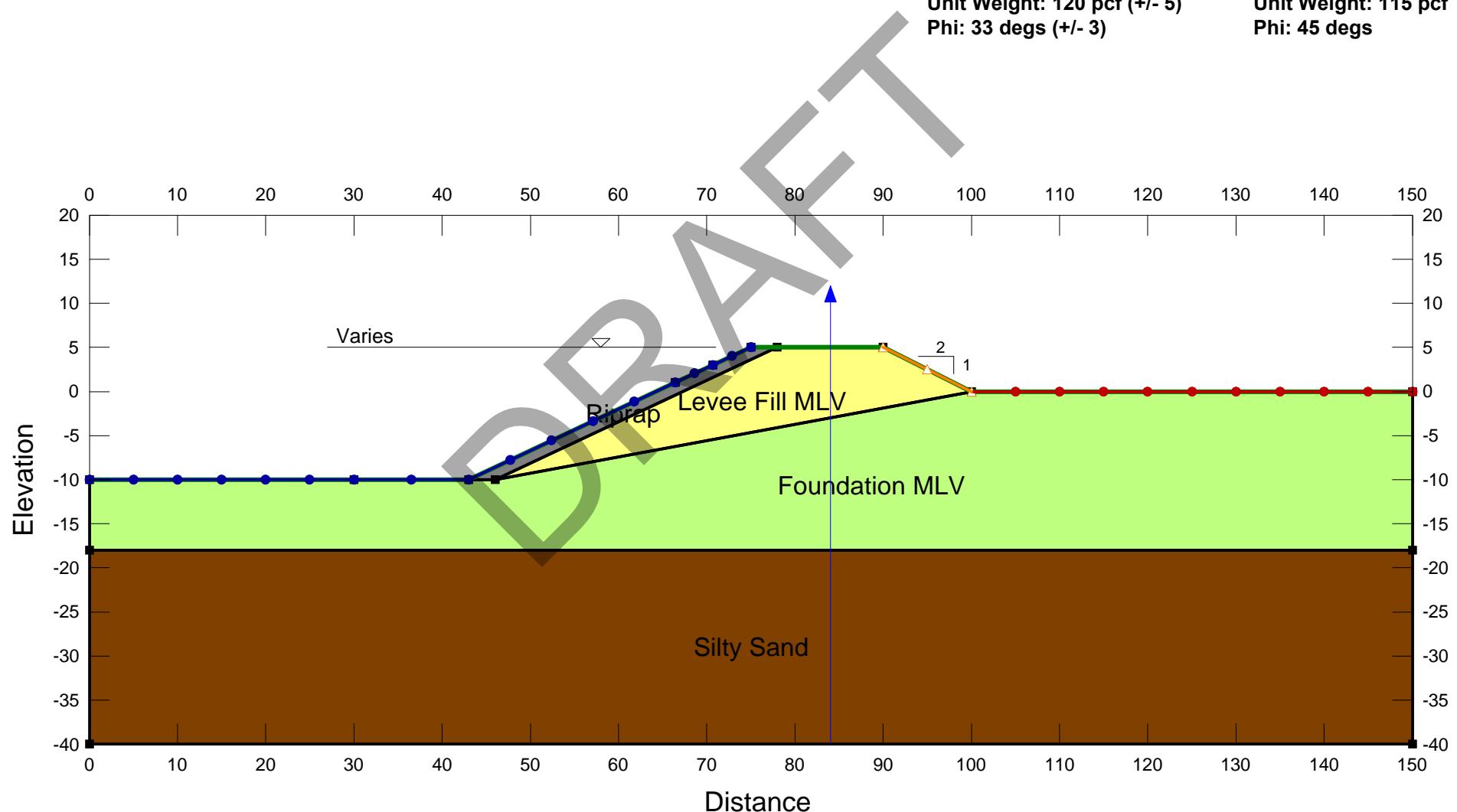
**McMillin Levee**  
**Puyallup River**  
**STA 39+25**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



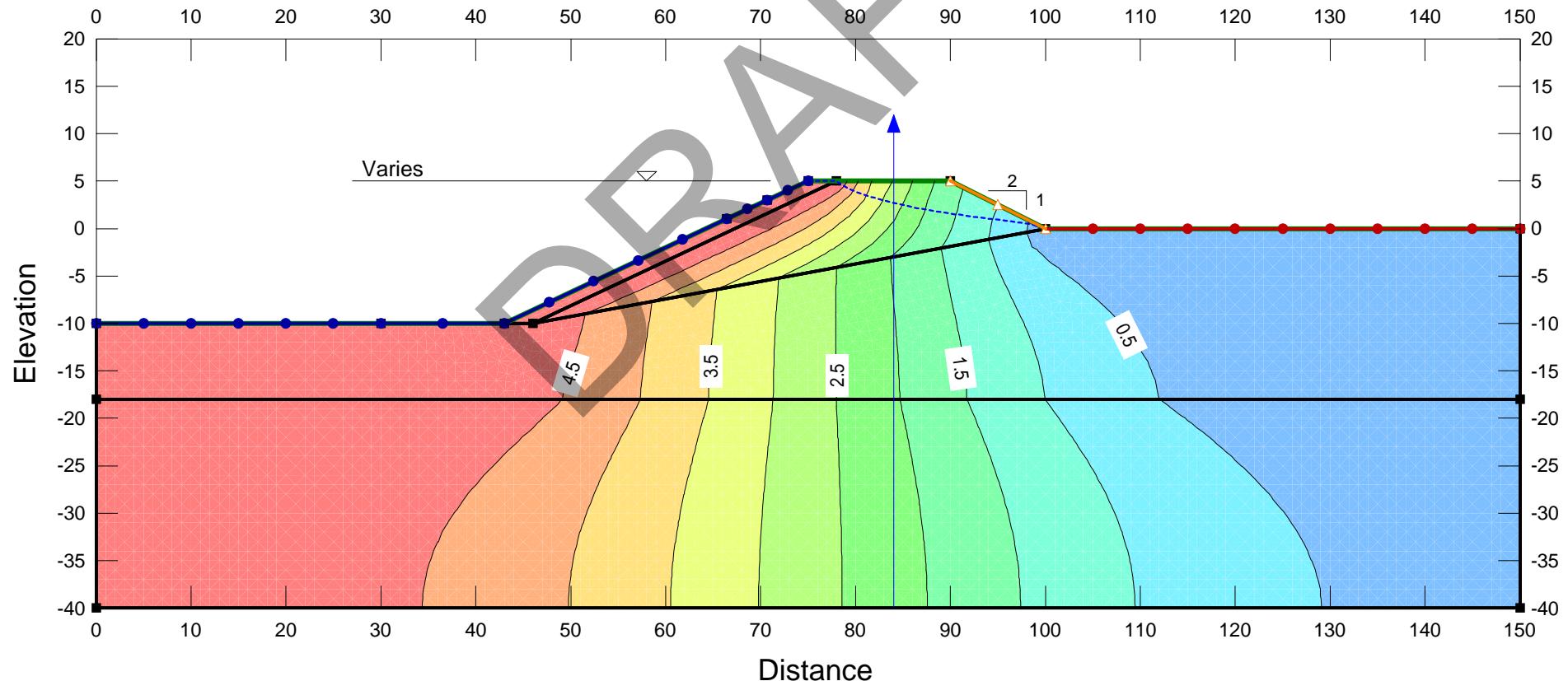
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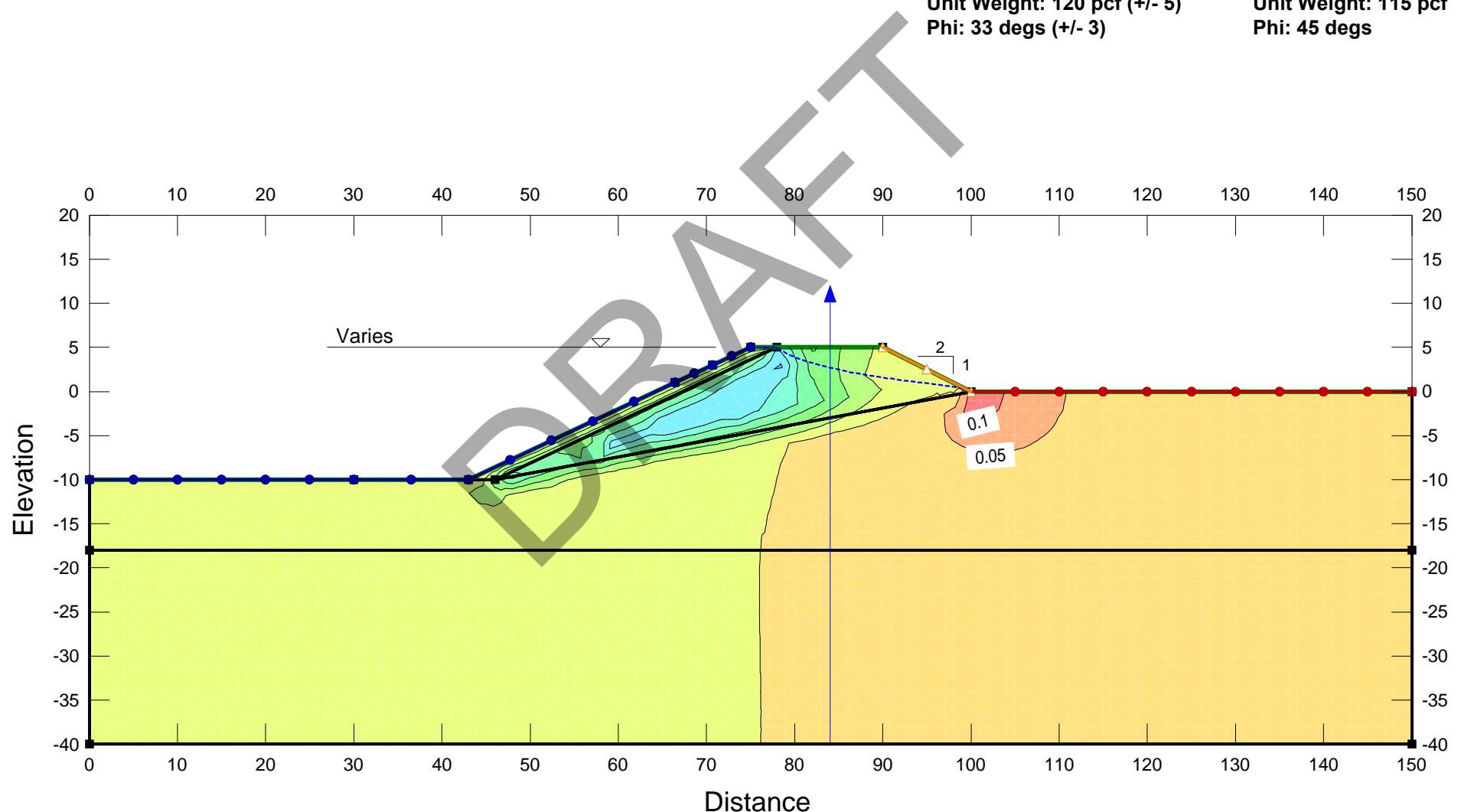
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Puyallup River  
STA 39+25

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KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
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Silty Sand  
 $\log(K\text{-Sat})$ : -3 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 120 pcf  
Phi: 33 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs



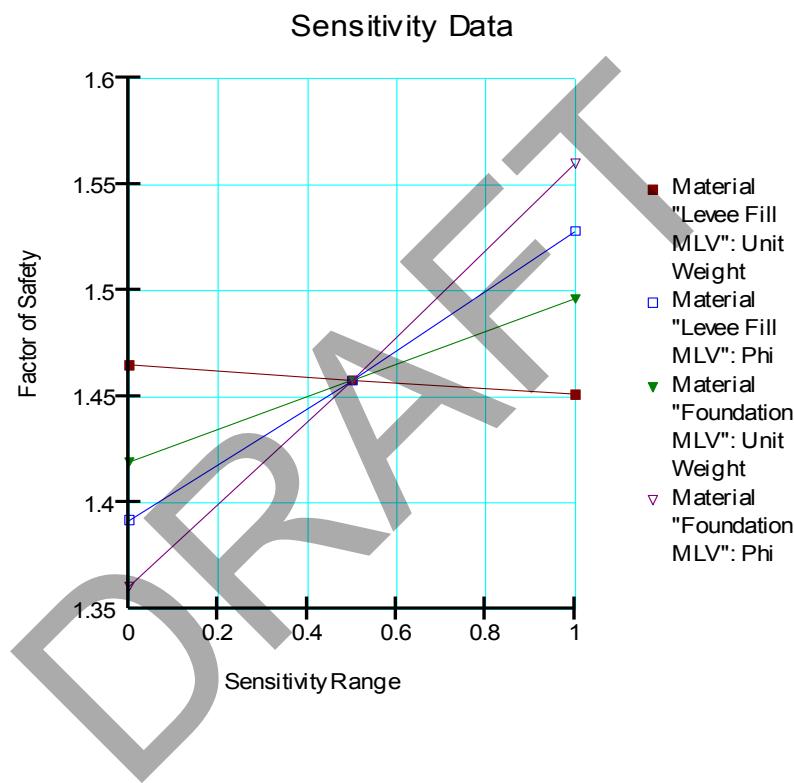
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	McMillin
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	McMillin cross section from STA 39+25. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	log( $K_h$ ) (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	log( $K_h$ ) (Foundation)	-2	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-2	120	33	0	0	1.46	
2	1	-3	120	33	1.5	-2	120	33	0	0	1.45	
3	2	-3	120	33	1.5	-2	120	33	0	0	1.45	0
4	1.5	-4	120	33	1.5	-2	120	33	0	0	1.52	
5	1.5	-2	120	33	1.5	-2	120	33	0	0	1.24	-0.28
6	1.5	-3	115	33	1.5	-2	120	33	0	0	1.47	
7	1.5	-3	125	33	1.5	-2	120	33	0	0	1.45	-0.01386
8	1.5	-3	120	30	1.5	-2	120	33	0	0	1.39	
9	1.5	-3	120	36	1.5	-2	120	33	0	0	1.53	0.13607
10	1.5	-3	120	33	1	-2	120	33	0	0	1.48	
11	1.5	-3	120	33	2	-2	120	33	0	0	1.43	-0.05
12	1.5	-3	120	33	1.5	-3	120	33	0	0	1.22	
13	1.5	-3	120	33	1.5	-1	120	33	0	0	1.46	0.24
14	1.5	-3	120	33	1.5	-2	115	33	0	0	1.42	
15	1.5	-3	120	33	1.5	-2	125	33	0	0	1.50	0.07682
16	1.5	-3	120	33	1.5	-2	120	30	0	0	1.36	
17	1.5	-3	120	33	1.5	-2	120	36	0	0	1.56	0.19899
18	1.5	-3	120	33	1.5	-2	120	33	0	0		
19	1.5	-3	120	33	1.5	-2	120	33	0	0		0
20	1.5	-3	120	33	1.5	-2	120	33	0	0		
21	1.5	-3	120	33	1.5	-2	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.225
Coefficient of variation of F,	$V_F$	0.154
Log normal reliability index,	$\beta_{LN}$	2.379
Reliability		0.991
Probability of failure		0.009

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.4650364	1.3920176	1.4193593	1.3609393
0.5	1.4578158	1.4578158	1.4578158	1.4578158
1	1.4511723	1.5280866	1.4961765	1.5599246



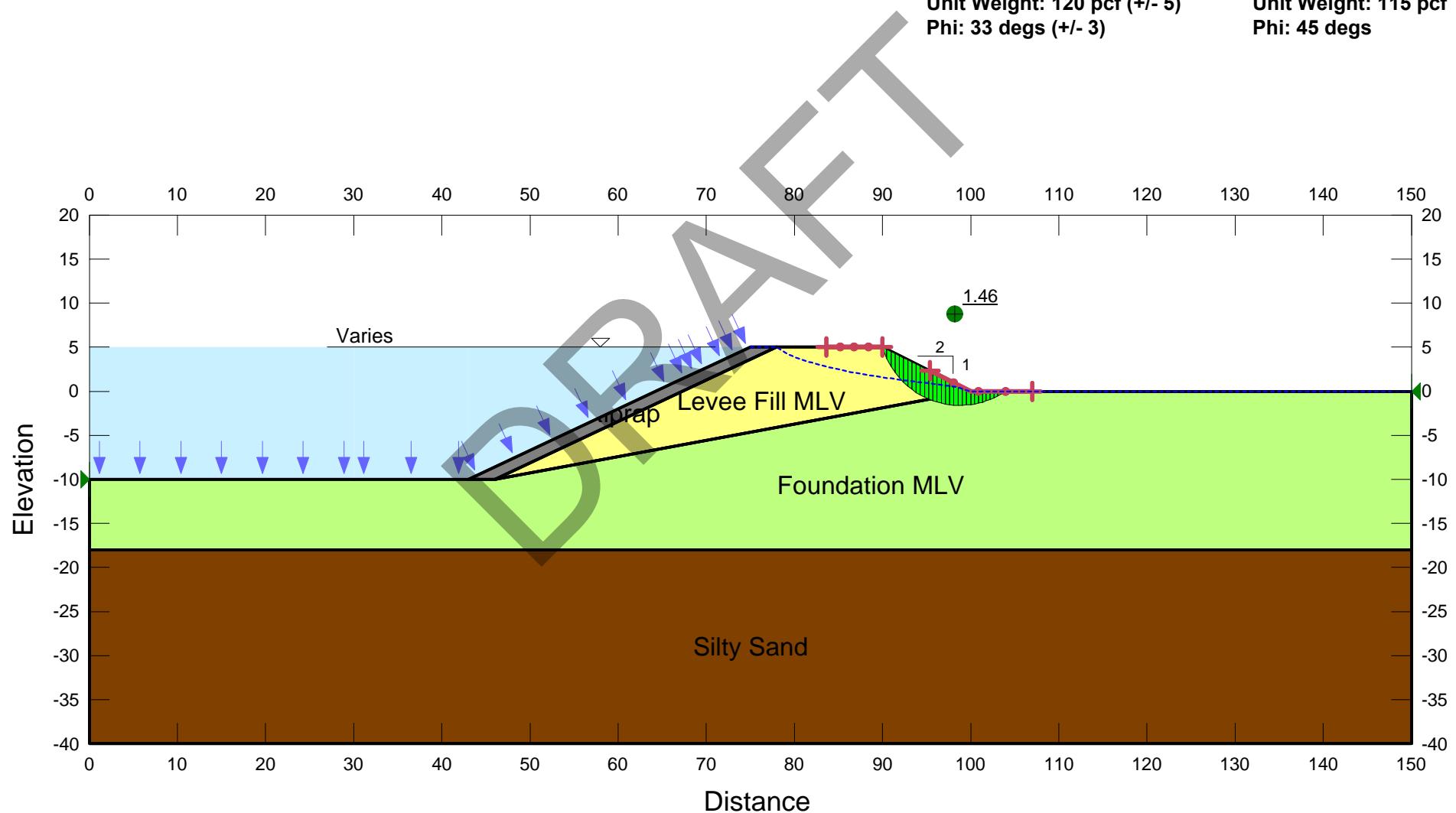
McMillin Levee  
Puyallup River  
STA 39+25

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Silty Sand  
 $\log(K\text{-Sat})$ : -3 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 120 pcf  
Phi: 33 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	McMillin
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	McMillin Levee cross section from STA 39+25. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-2	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-2	0	0	0	0	0	11.54	
2	52.6	1.5	1.5	-3	-2	0	0	0	0	0	10.54	
3	62.6	1.5	1.5	-3	-2	0	0	0	0	0	12.54	2.00321
4	57.6	1	1.5	-3	-2	0	0	0	0	0	11.54	
5	57.6	2	1.5	-3	-2	0	0	0	0	0	11.54	0
6	57.6	1.5	1	-3	-2	0	0	0	0	0	11.54	
7	57.6	1.5	2	-3	-2	0	0	0	0	0	10.26	-1.28205
8	57.6	1.5	1.5	-4	-2	0	0	0	0	0	14.54	
9	57.6	1.5	1.5	-2	-2	0	0	0	0	0	7.13	-7.40313
10	57.6	1.5	1.5	-3	-3	0	0	0	0	0	6.52	
11	57.6	1.5	1.5	-3	-1	0	0	0	0	0	11.83	5.31081
12	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-2	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	4.708
Coefficient of variation of F,	$V_F$	0.408
Log normal reliability index,	$\beta_{LN}$	6.036
Reliability		1.000
Probability of failure		7.9E-10

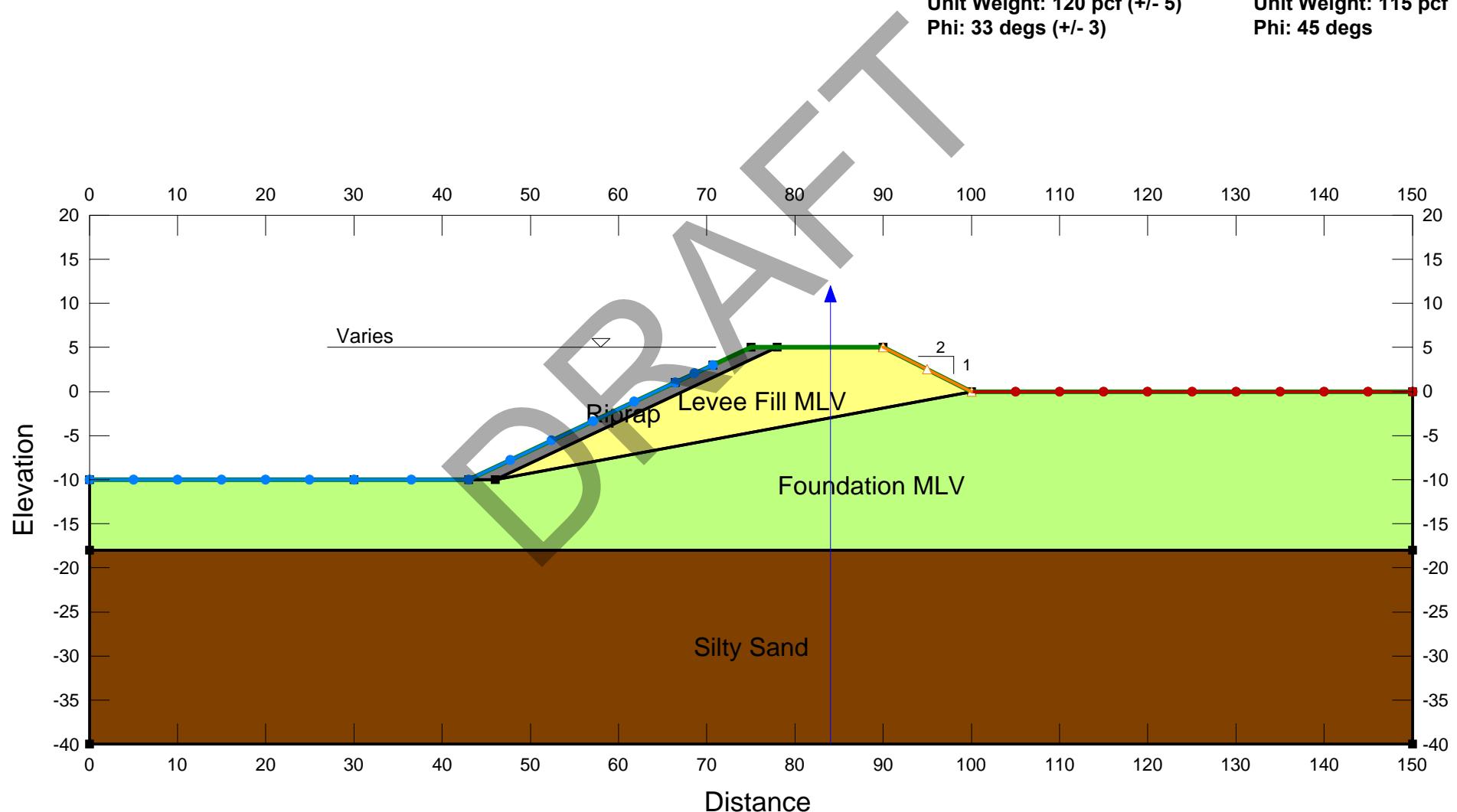
**McMillin Levee**  
**Puyallup River**  
**STA 39+25**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



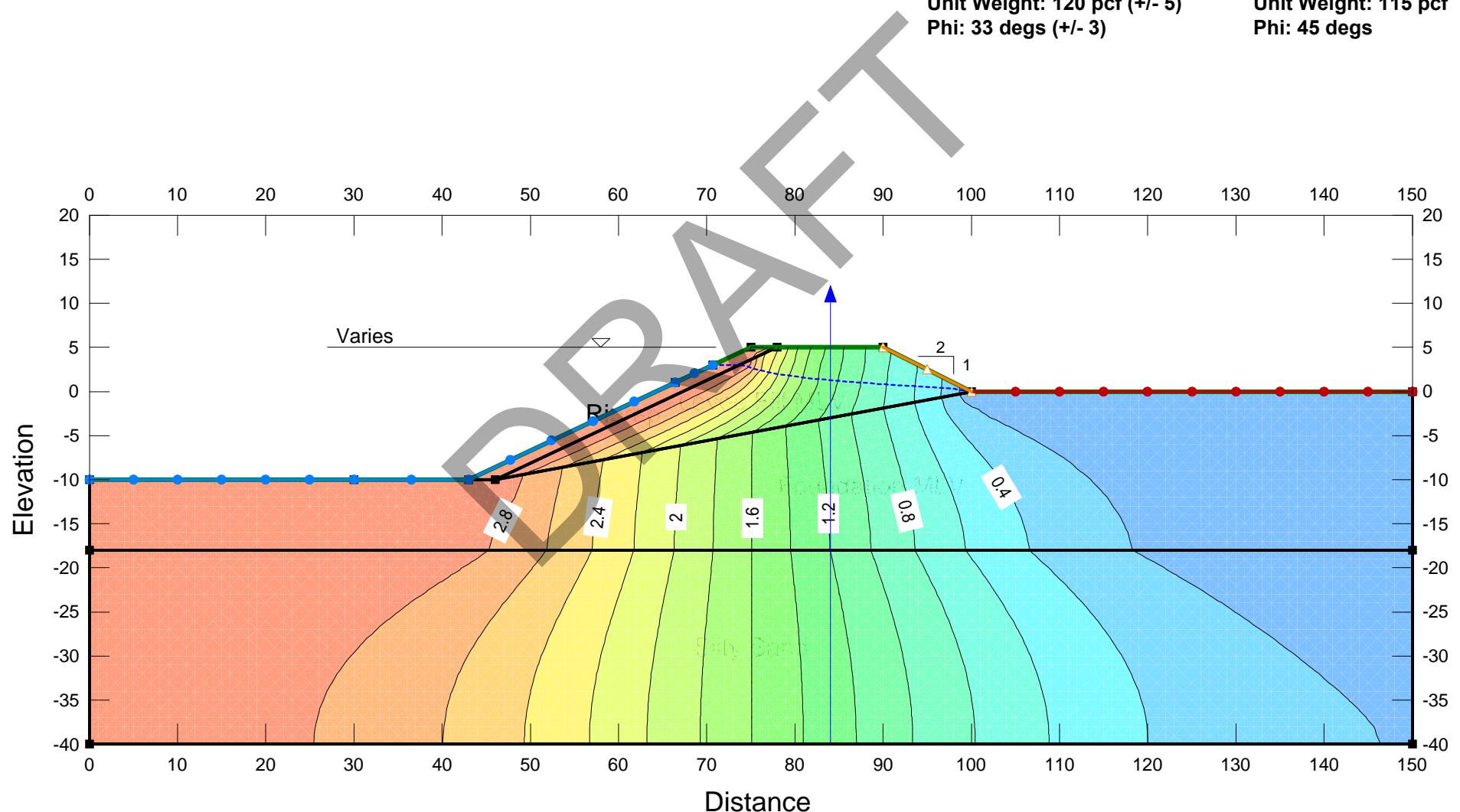
**McMillin Levee**  
**Puyallup River**  
**STA 39+25**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



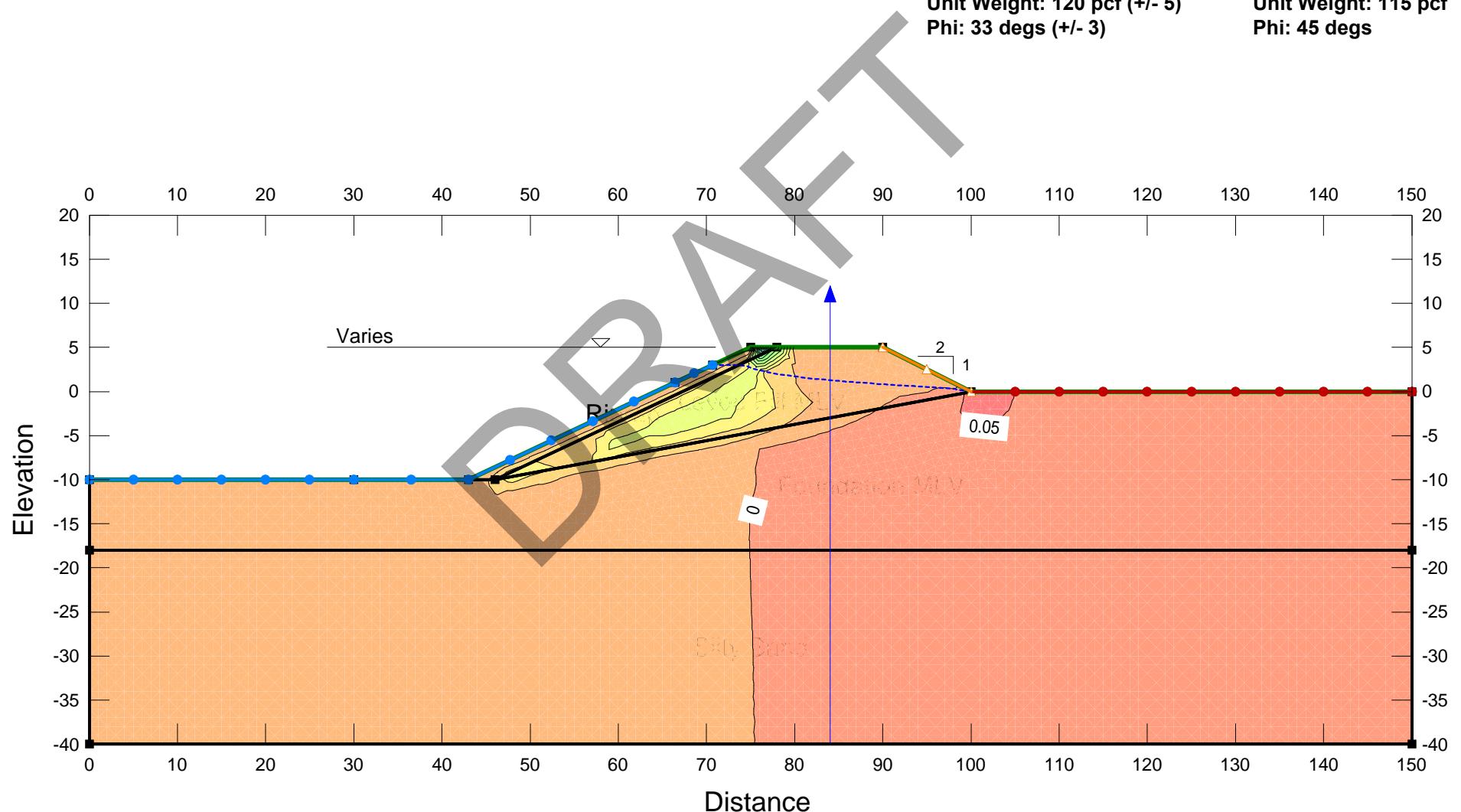
McMillin Levee  
Puyallup River  
STA 39+25

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
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Silty Sand  
 $\log(K\text{-Sat})$ : -3 cm/s  
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Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs



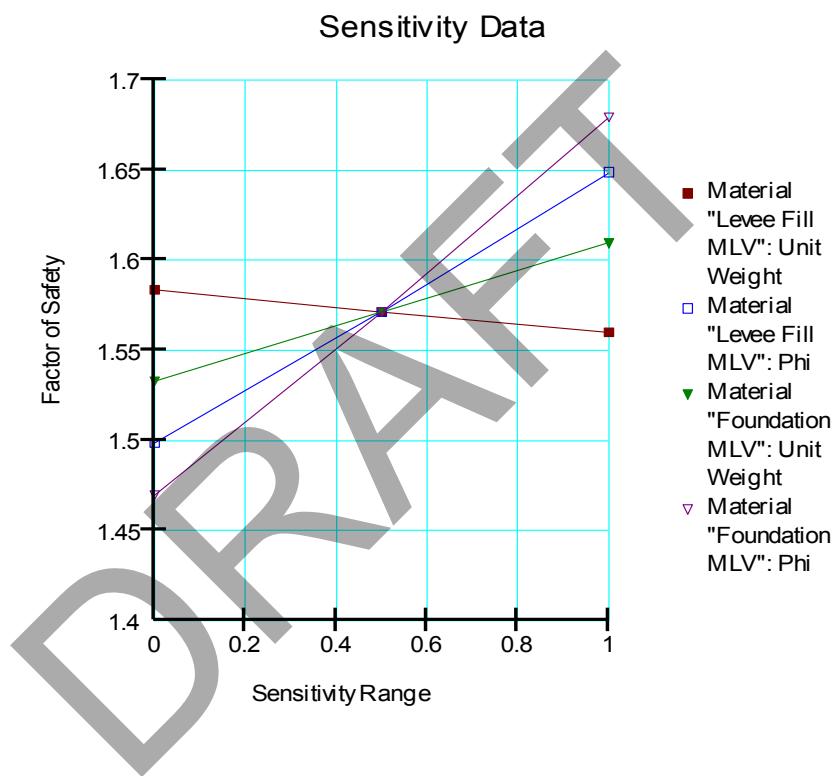
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	McMillin
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	McMillin Levee cross section from STA 39+25. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-2	120	33	0	0	1.57	
2	1	-3	120	33	1.5	-2	120	33	0	0	1.57	
3	2	-3	120	33	1.5	-2	120	33	0	0	1.57	0
4	1.5	-4	120	33	1.5	-2	120	33	0	0	1.59	
5	1.5	-2	120	33	1.5	-2	120	33	0	0	1.48	-0.11
6	1.5	-3	115	33	1.5	-2	120	33	0	0	1.58	
7	1.5	-3	125	33	1.5	-2	120	33	0	0	1.56	-0.02357
8	1.5	-3	120	30	1.5	-2	120	33	0	0	1.50	
9	1.5	-3	120	36	1.5	-2	120	33	0	0	1.65	0.15025
10	1.5	-3	120	33	1	-2	120	33	0	0	1.58	
11	1.5	-3	120	33	2	-2	120	33	0	0	1.55	-0.03
12	1.5	-3	120	33	1.5	-3	120	33	0	0	1.46	
13	1.5	-3	120	33	1.5	-1	120	33	0	0	1.57	0.11
14	1.5	-3	120	33	1.5	-2	115	33	0	0	1.53	
15	1.5	-3	120	33	1.5	-2	125	33	0	0	1.61	0.07659
16	1.5	-3	120	33	1.5	-2	120	30	0	0	1.47	
17	1.5	-3	120	33	1.5	-2	120	36	0	0	1.68	0.20967
18	1.5	-3	120	33	1.5	-2	120	33	0	0		
19	1.5	-3	120	33	1.5	-2	120	33	0	0		0
20	1.5	-3	120	33	1.5	-2	120	33	0	0		
21	1.5	-3	120	33	1.5	-2	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.157
Coefficient of variation of F,	$V_F$	0.100
Log normal reliability index,	$\beta_{LN}$	4.497
Reliability		1.000
Probability of failure		3.4E-06

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.5835426	1.4986547	1.5329252	1.4698015
0.5	1.5713221	1.5713221	1.5713221	1.5713221
1	1.5599684	1.6488997	1.6095171	1.6794735



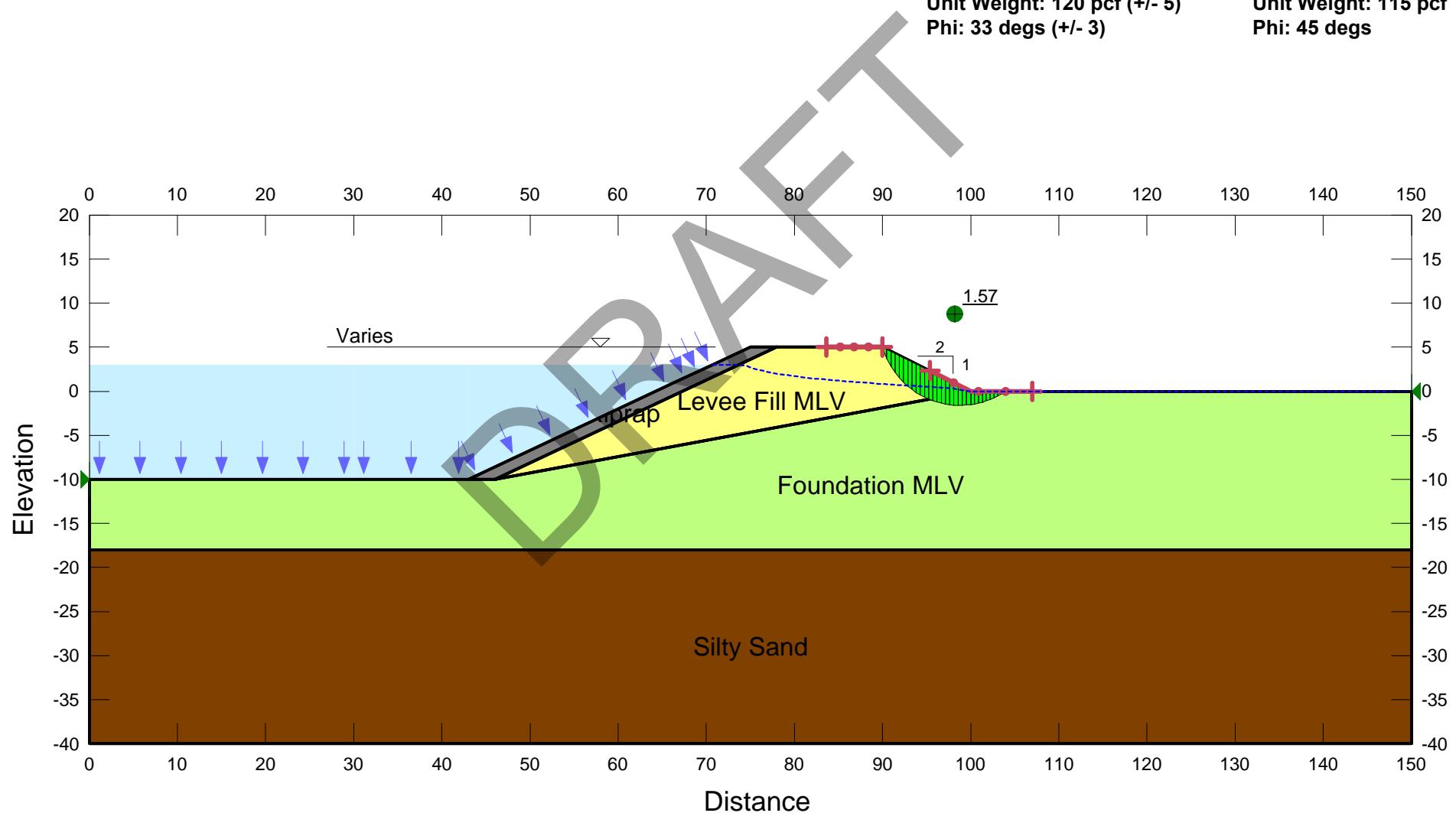
**McMillin Levee**  
**Puyallup River**  
**STA 39+25**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	McMillin
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	McMillin Levee cross section from STA 39+25. Water Surface Elevation is 4 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-2	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-2	0	0	0	0	0	15.65	
2	52.6	1.5	1.5	-3	-2	0	0	0	0	0	14.29	
3	62.6	1.5	1.5	-3	-2	0	0	0	0	0	17.00	2.71621
4	57.6	1	1.5	-3	-2	0	0	0	0	0	15.38	
5	57.6	2	1.5	-3	-2	0	0	0	0	0	15.38	0
6	57.6	1.5	1	-3	-2	0	0	0	0	0	15.38	
7	57.6	1.5	2	-3	-2	0	0	0	0	0	15.38	0
8	57.6	1.5	1.5	-4	-2	0	0	0	0	0	12.15	
9	57.6	1.5	1.5	-2	-2	0	0	0	0	0	15.38	3.23887
10	57.6	1.5	1.5	-3	-3	0	0	0	0	0	21.47	
11	57.6	1.5	1.5	-3	-1	0	0	0	0	0	36.92	15.4562
12	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-2	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	8.012
Coefficient of variation of F,	$V_F$	0.512
Log normal reliability index,	$\beta_{LN}$	5.458
Reliability		1.000
Probability of failure		2.4E-08

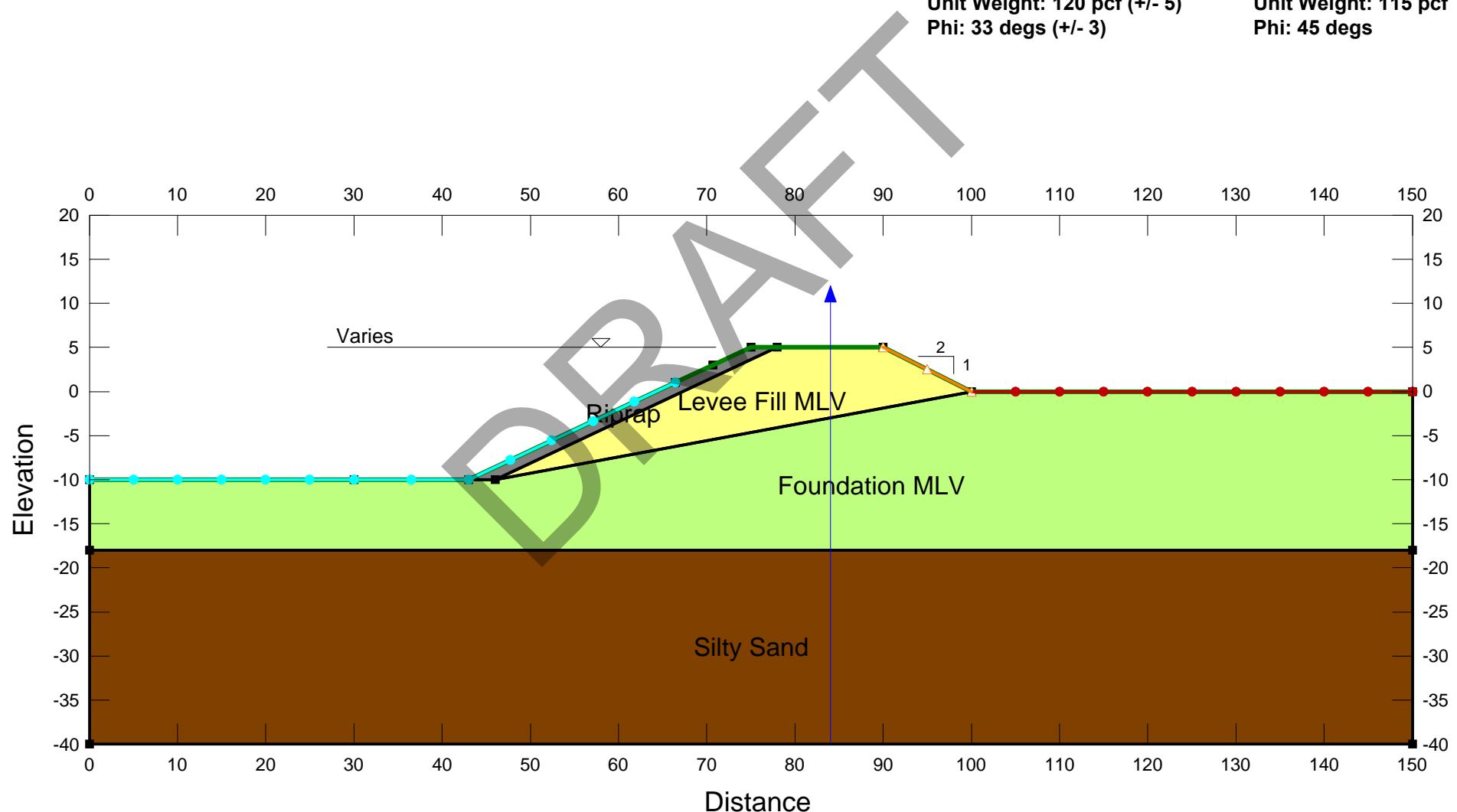
**McMillin Levee**  
**Puyallup River**  
**STA 39+25**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



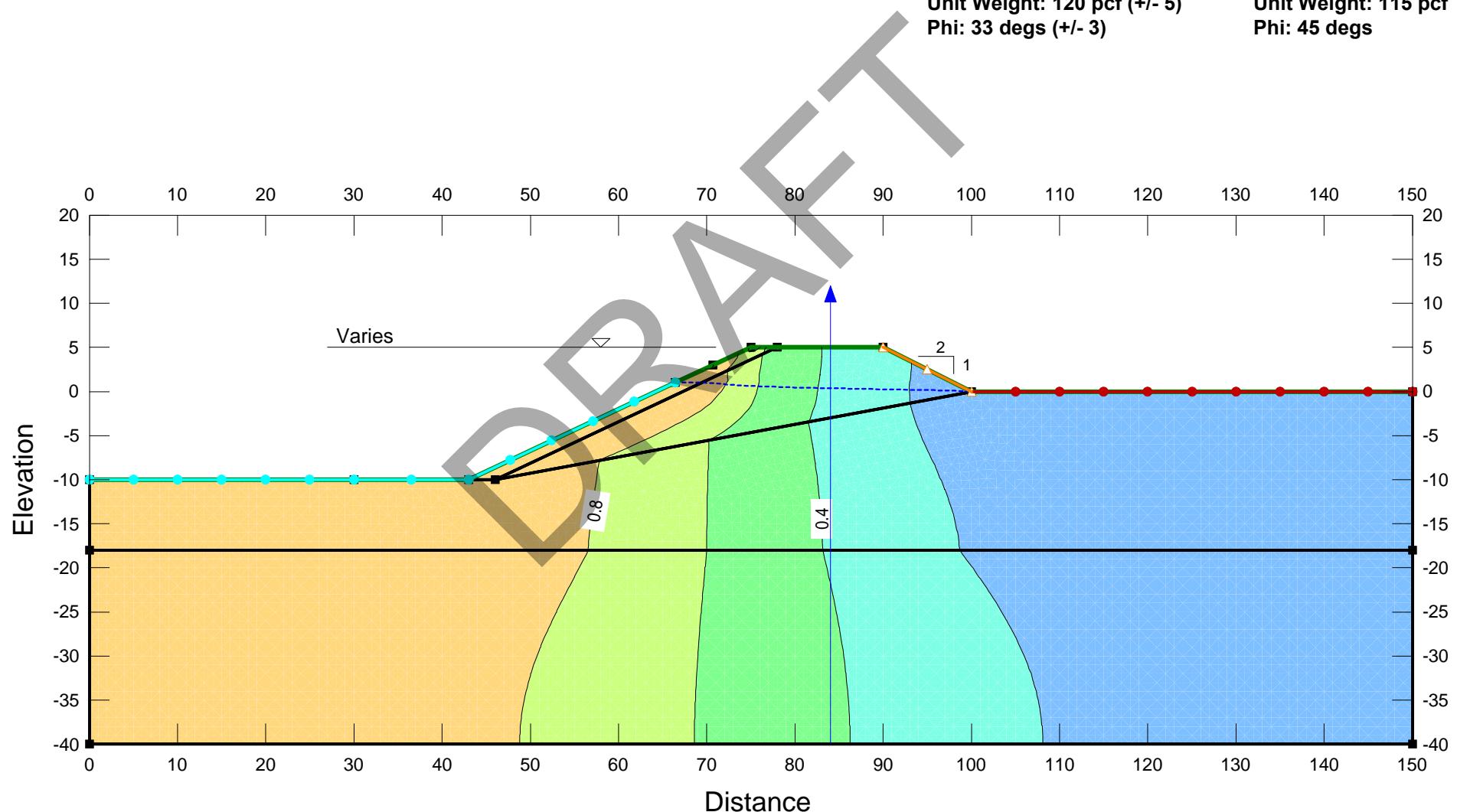
McMillin Levee  
Puyallup River  
STA 39+25

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Silty Sand  
 $\log(K\text{-Sat})$ : -3 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 120 pcf  
Phi: 33 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs



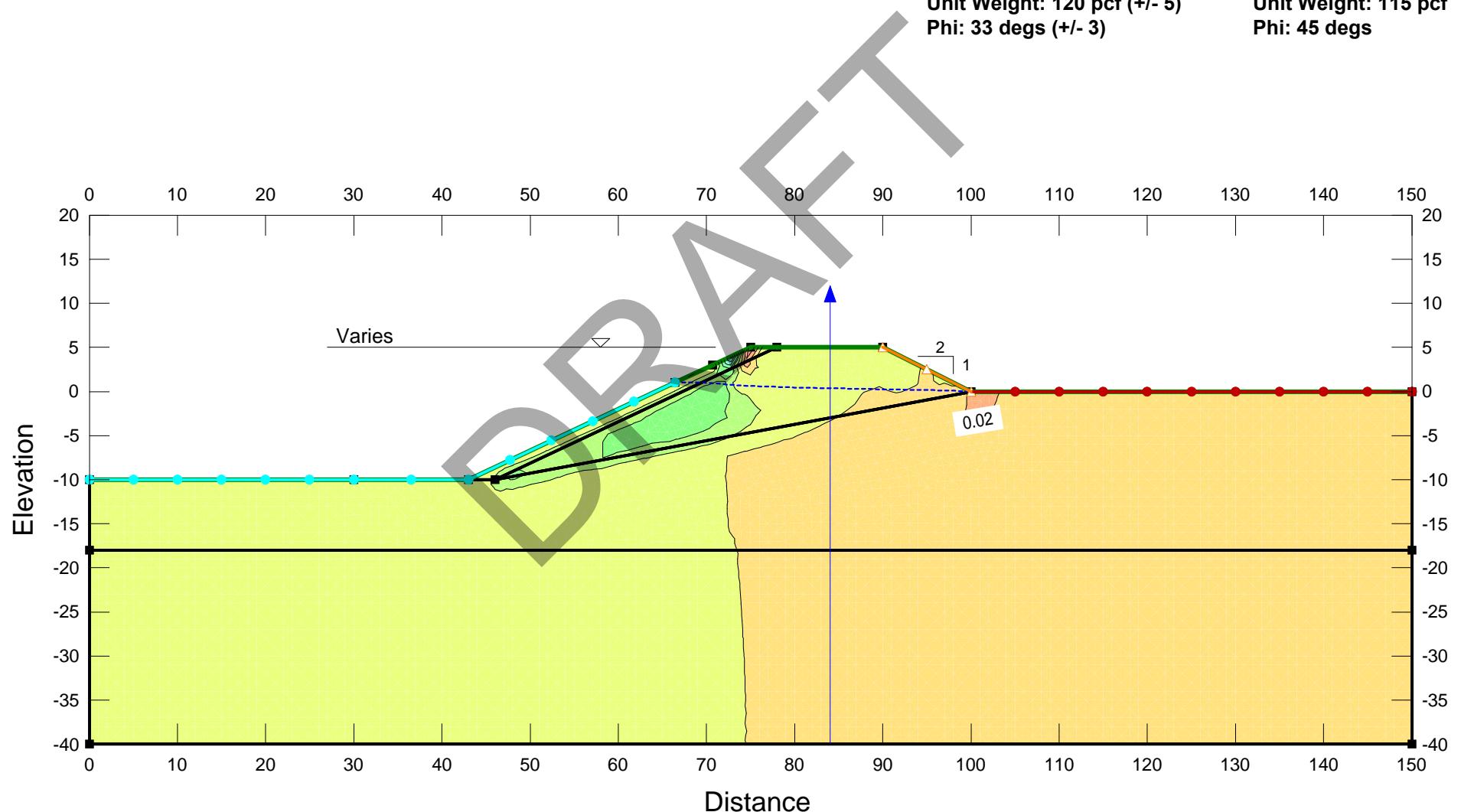
McMillin Levee  
Puyallup River  
STA 39+25

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
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Silty Sand  
 $\log(K\text{-Sat})$ : -3 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 120 pcf  
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Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs



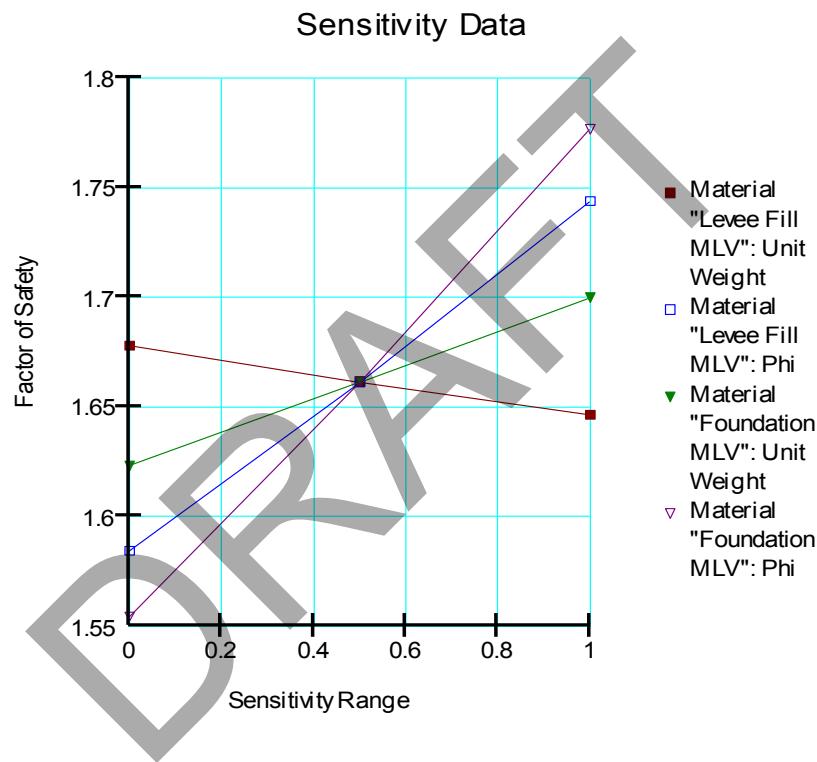
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	McMillin
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	McMillin Levee cross section from STA 39+25. Water Surface Elevation is 4 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	log( $K_h$ ) (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	log( $K_h$ ) (Foundation)	-2	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-2	120	33	0	0	1.66	
2	1	-3	120	33	1.5	-2	120	33	0	0	1.65	
3	2	-3	120	33	1.5	-2	120	33	0	0	1.65	0
4	1.5	-4	120	33	1.5	-2	120	33	0	0	1.66	
5	1.5	-2	120	33	1.5	-2	120	33	0	0	1.63	-0.03
6	1.5	-3	115	33	1.5	-2	120	33	0	0	1.68	
7	1.5	-3	125	33	1.5	-2	120	33	0	0	1.65	-0.03159
8	1.5	-3	120	30	1.5	-2	120	33	0	0	1.58	
9	1.5	-3	120	36	1.5	-2	120	33	0	0	1.74	0.15957
10	1.5	-3	120	33	1	-2	120	33	0	0	1.66	
11	1.5	-3	120	33	2	-2	120	33	0	0	1.65	-0.01
12	1.5	-3	120	33	1.5	-3	120	33	0	0	1.63	
13	1.5	-3	120	33	1.5	-1	120	33	0	0	1.66	0.03
14	1.5	-3	120	33	1.5	-2	115	33	0	0	1.62	
15	1.5	-3	120	33	1.5	-2	125	33	0	0	1.70	0.07666
16	1.5	-3	120	33	1.5	-2	120	30	0	0	1.55	
17	1.5	-3	120	33	1.5	-2	120	36	0	0	1.78	0.22226
18	1.5	-3	120	33	1.5	-2	120	33	0	0		
19	1.5	-3	120	33	1.5	-2	120	33	0	0		0
20	1.5	-3	120	33	1.5	-2	120	33	0	0		
21	1.5	-3	120	33	1.5	-2	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.145
Coefficient of variation of F,	$V_F$	0.087
Log normal reliability index,	$\beta_{LN}$	5.801
Reliability		1.000
Probability of failure		3.3E-09

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.6779716	1.5843882	1.6231541	1.5544729
0.5	1.6614947	1.6614947	1.6614947	1.6614947
1	1.6463785	1.7439593	1.6998135	1.7767295



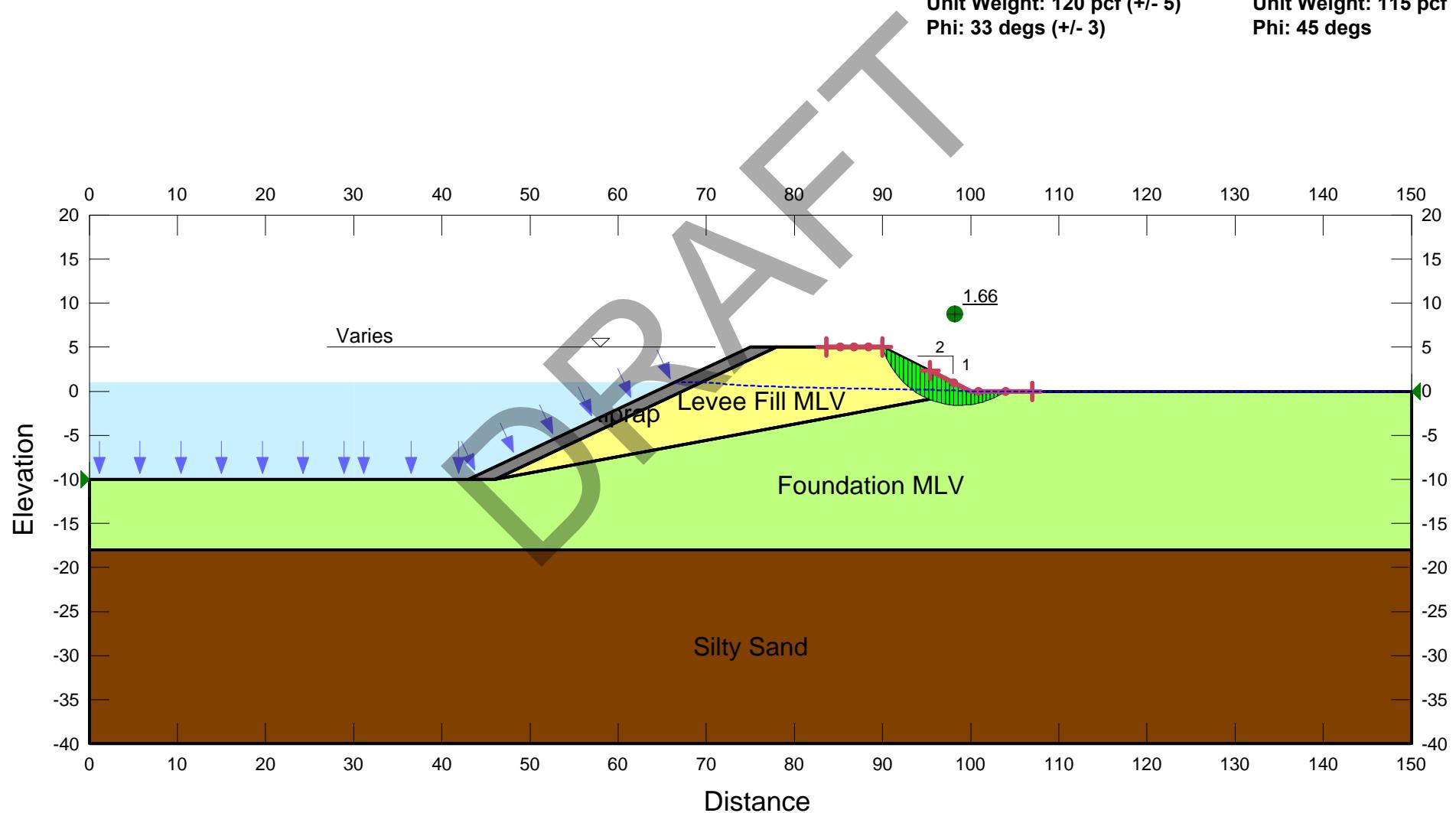
McMillin Levee  
Puyallup River  
STA 39+25

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

Silty Sand  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

Location:	Pierce County, Washington
River:	Puyallup River
Levee Segment Name:	Neadham Road
Station:	8+51

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is rated acceptable per USACE guidance.

#### Levee Geometry

Crown Width (W)	22 Feet
Landward Levee Height (H)	9 Feet
Riverward Slope (R)	3.1 H:1V
Landward Slope (L)	5.3 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	9 Feet
Breach Width at Top of Levee	202 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.75 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation assumed to be a homogeneous coarse alluvium.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
Loose / Soft		Low
Medium		Medium
X Dense / Stiff	X	High

**Remarks:** Levee embankment material estimated to be high density engineered fill. GRAVEL with sand and trace silt (GP).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
430.34	1.00
430.34	0.09
428.34	0.03
426.34	0.01
421.34	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

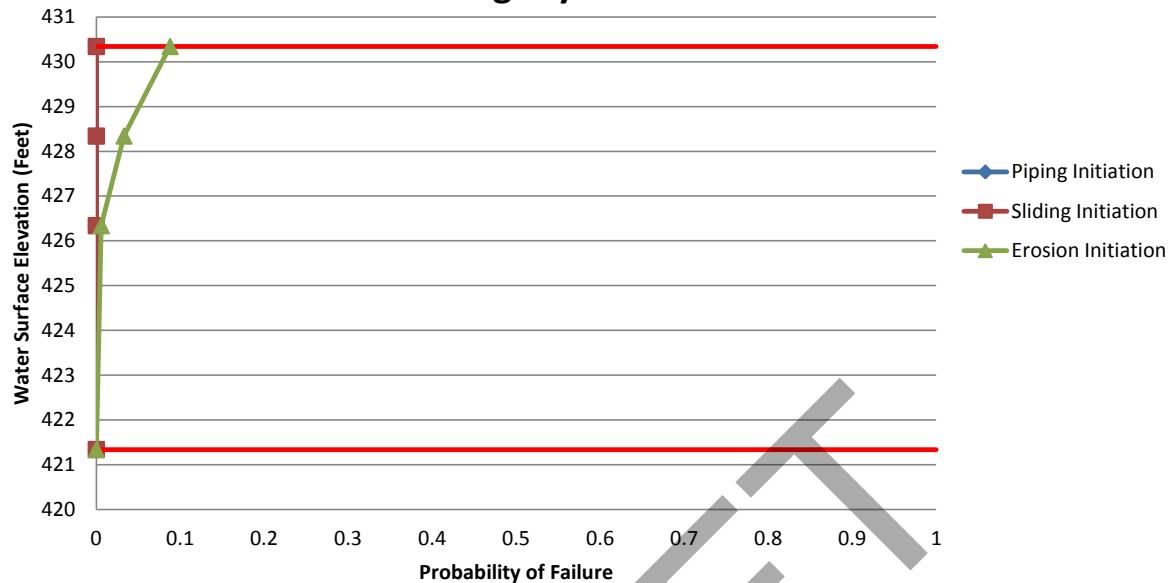
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

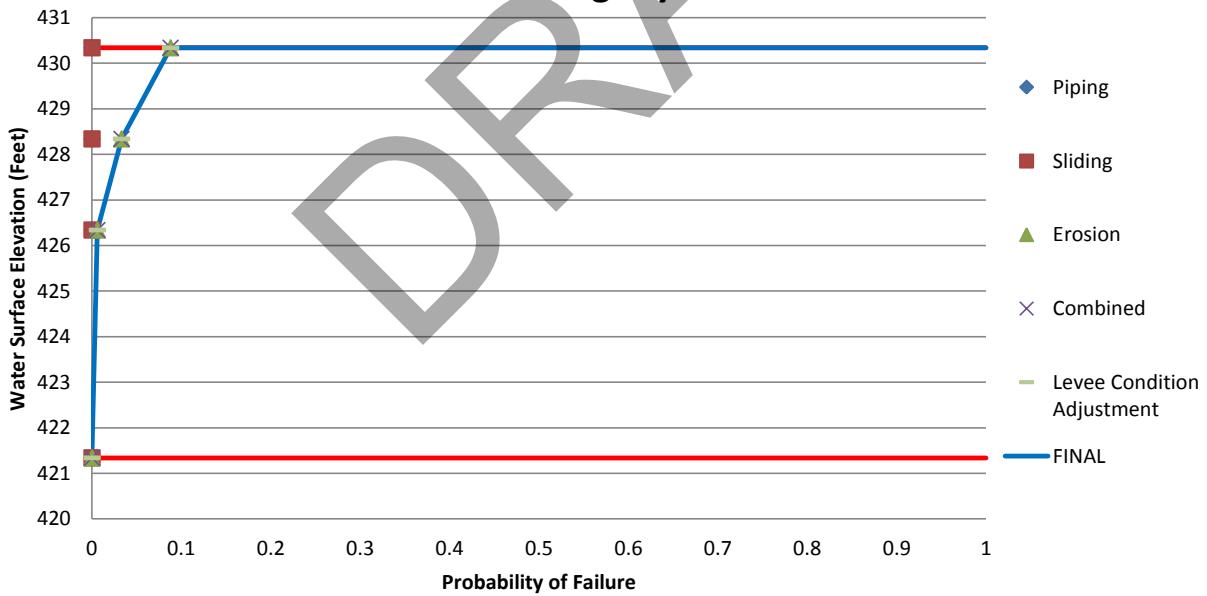
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve

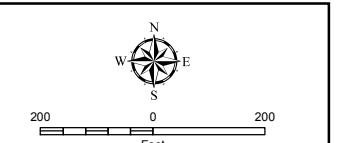
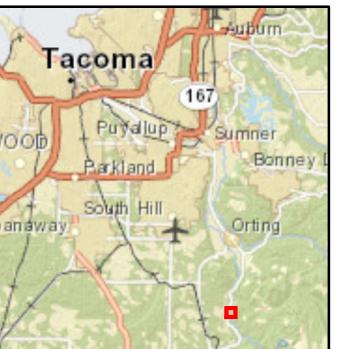


*Remarks:* The final levee fragility curve for the Neadham Road levee was based on engineering judgement for the piping and sliding failure modes. The gentle landward slope and levee material is assumed to be stable for all water surface elevations. Seepage and piping is not a likely failure mode for this levee section. Levee scour analysis was performed and the results are reflected in this fragility curve. Finally, flood fighting adjustment factors were ignored in this analysis.

# Neadham Road Levee - Puyallup River



**Location Map**



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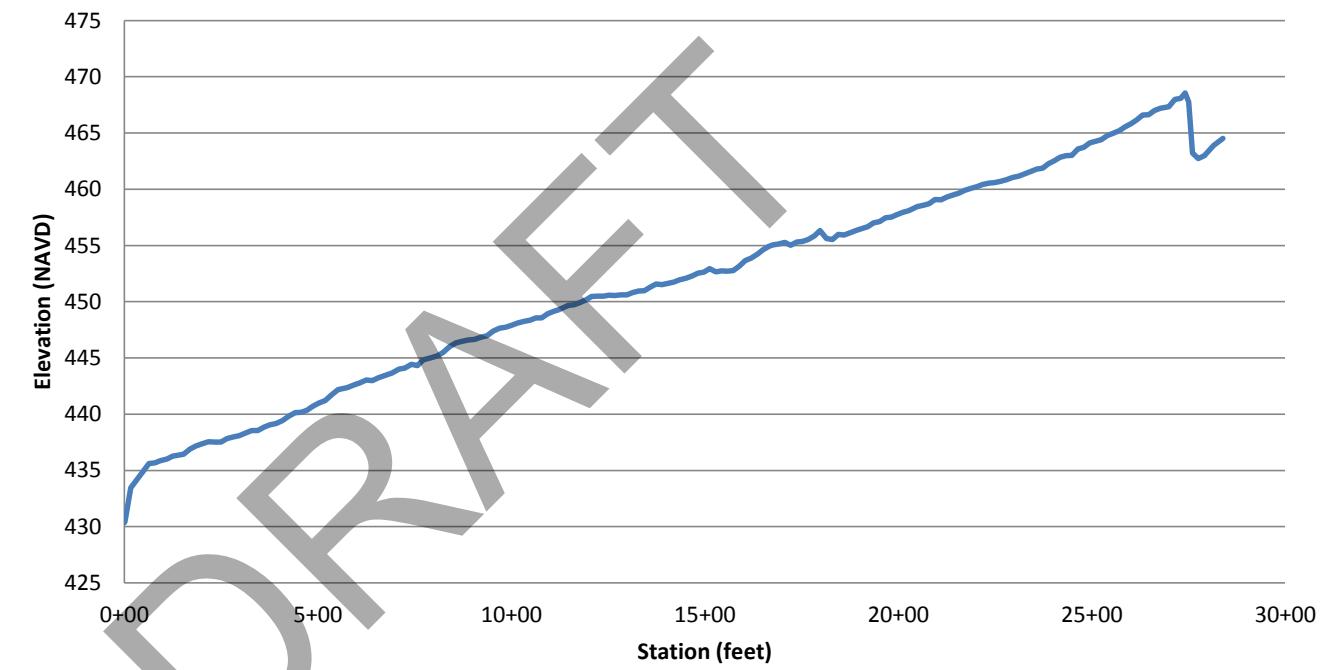
## **Neadham Road Levee**

**Puyallup River**

<b>Min</b>	430.34
<b>Max</b>	468.55

<b>Station Begin</b>	0+00
<b>Station End</b>	28+39

### **Levee Profile**



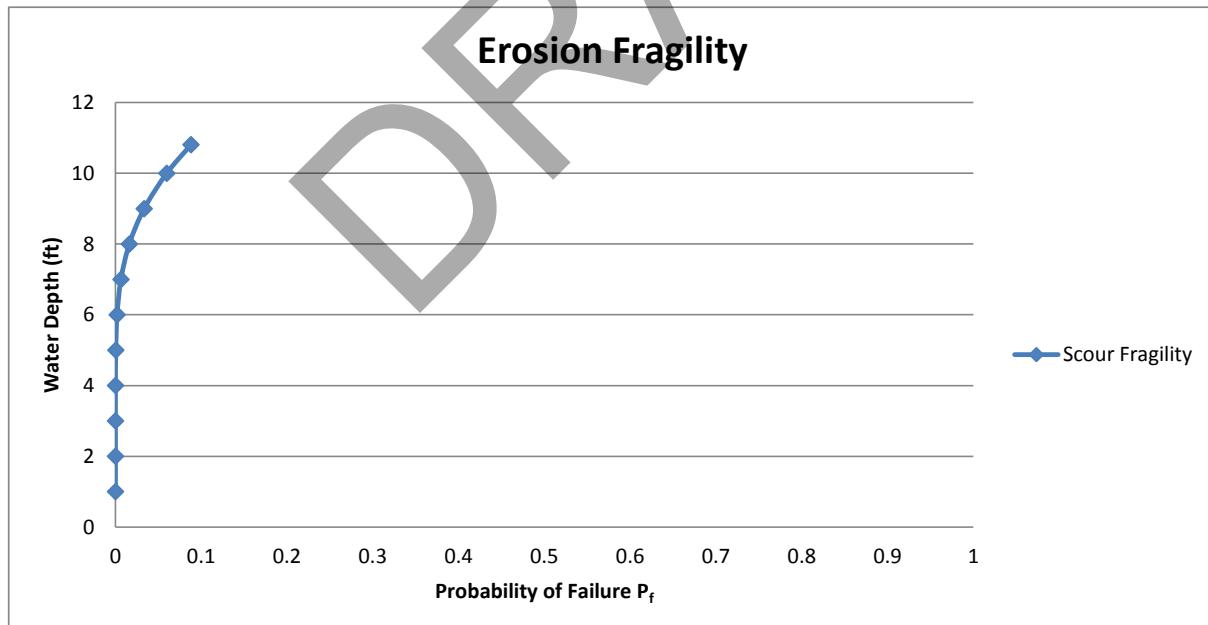
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Neadham Road Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.012	CV(s) =	0.1	0.0012
Manning's "n"	n =	0.055	CV(n) =	0.15	0.00825
Scouring Velocity		$V_{crit} =$	20.43	$CV(V_{crit})$	0.2
					4.09

Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
1	2.960	0.1581139		-1.931979272	0.254950976	-7.57785	1.7567E-14
2	4.698	0.1581139		-1.469881152	0.254950976	-5.76535	4.0745E-09
3	6.156	0.1581139		-1.199571108	0.254950976	-4.7051	1.2687E-06
4	7.458	0.1581139		-1.007783031	0.254950976	-3.95285	3.8613E-05
5	8.654	0.1581139		-0.859020664	0.254950976	-3.36936	0.00037672
6	9.773	0.1581139		-0.737472959	0.254950976	-2.89261	0.0019103
7	10.830	0.1581139		-0.634705839	0.254950976	-2.48952	0.00639577
8	11.839	0.1581139		-0.545684911	0.254950976	-2.14035	0.01616315
9	12.806	0.1581139		-0.467162887	0.254950976	-1.83236	0.03344863
10	13.738	0.1581139		-0.396922543	0.254950976	-1.55686	0.05975207
10.81	14.470	0.1581139		-0.344998184	0.254950976	-1.35319	0.0879968



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

*North Levee Road Cross Section Model & Erosion Analysis*

#### General Information

Location:	Pierce County, Washington
River:	Puyallup River
Levee Segment Name:	North Levee Road
Station:	57+80

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Erosion probability doubled due to ageing concrete panels.

#### Levee Geometry

Crown Width (W)	25 Feet
Landward Levee Height (H)	10 Feet
Riverward Slope (R)	3.6 H:1V
Landward Slope (L)	2.6 H:1V

#### Breach Characteristics

Levee Material Type	Generally Cohesionless
X	Generally Cohesive
Breach Depth	10 Feet
Breach Width at Top of Levee	224 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.95 Hours*

\*SERRI Report 70015-001

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
27.78	1.00
27.77	0.58
24.78	0.34
21.78	0.15
17.78	0.04

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

#### Landward Slope Instability Failure Mode

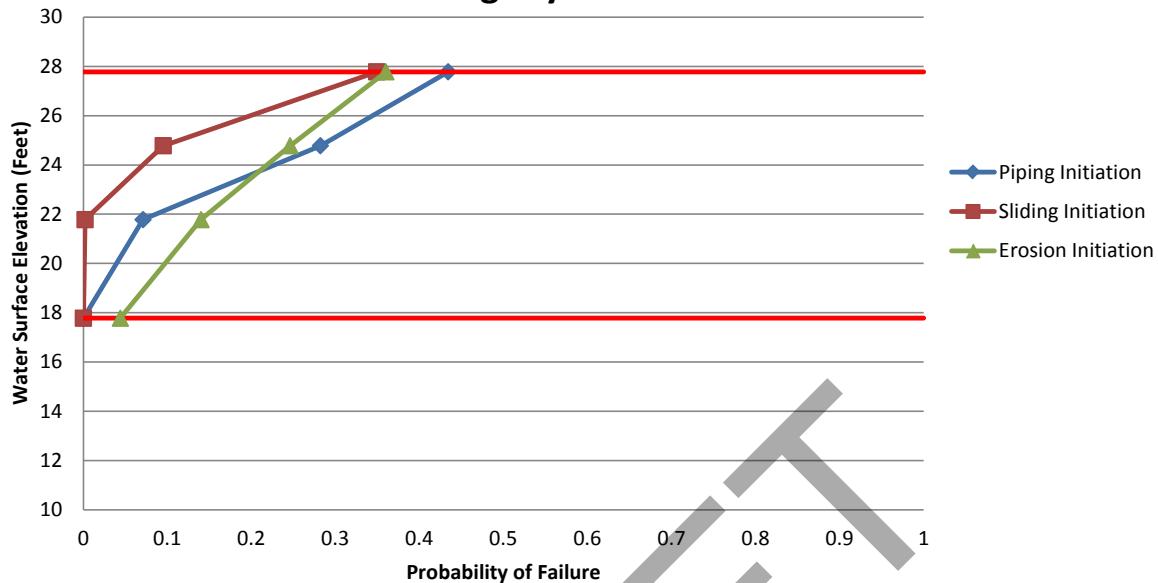
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

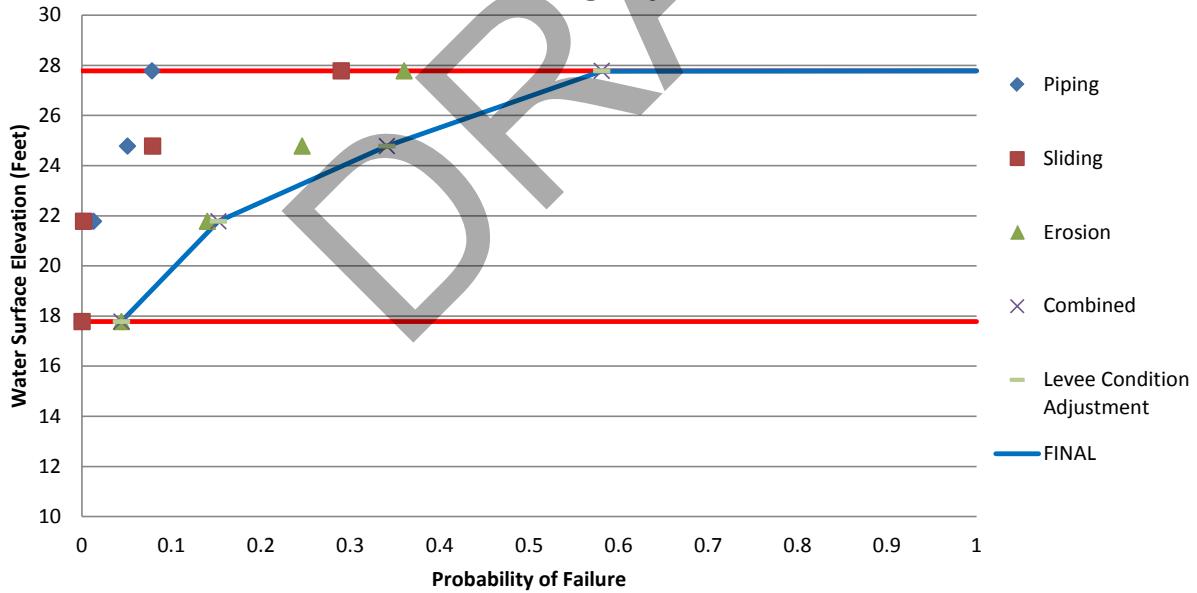
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



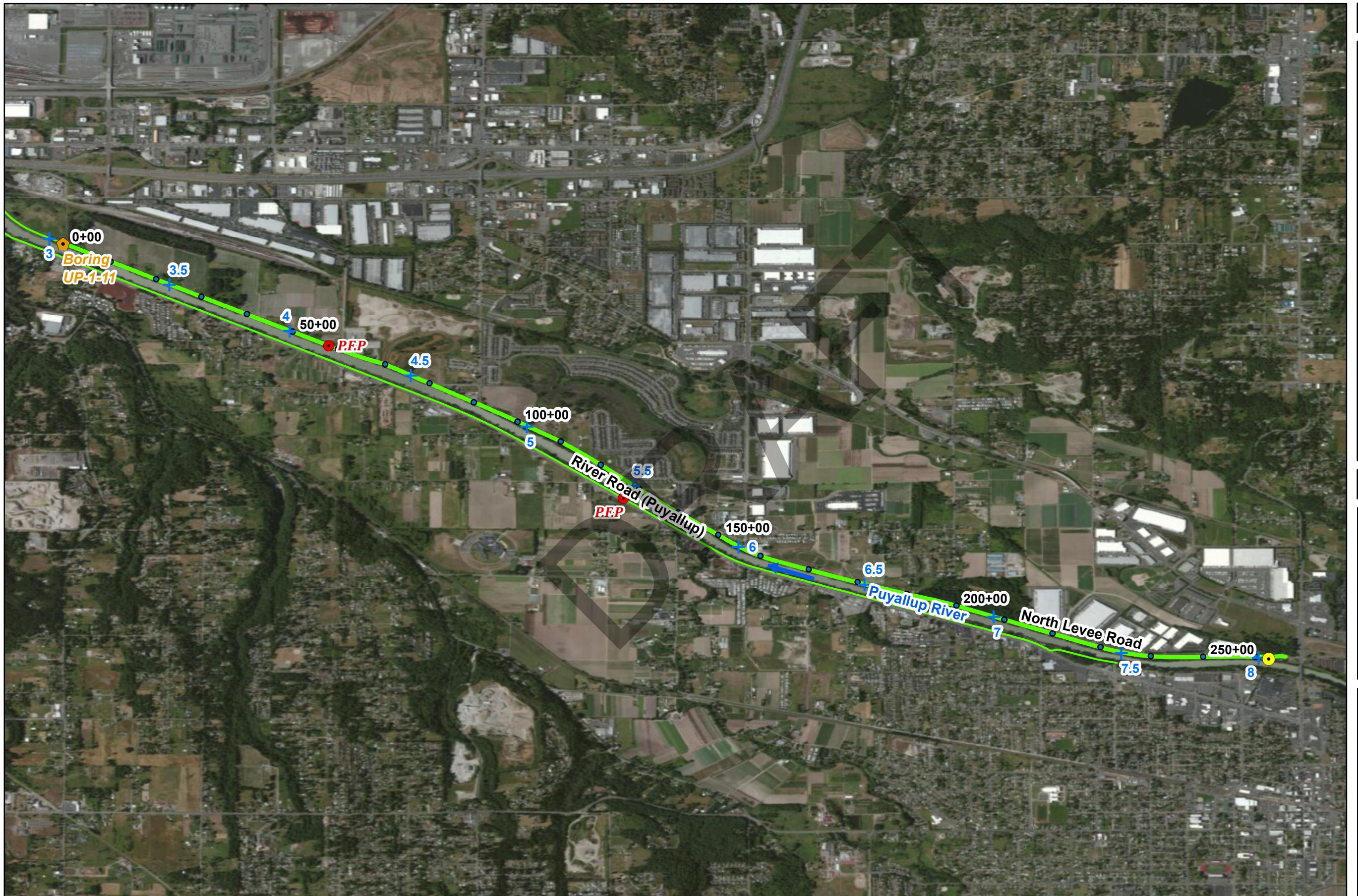
*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the North Levee Road Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# North Levee Road Levee - Puyallup River



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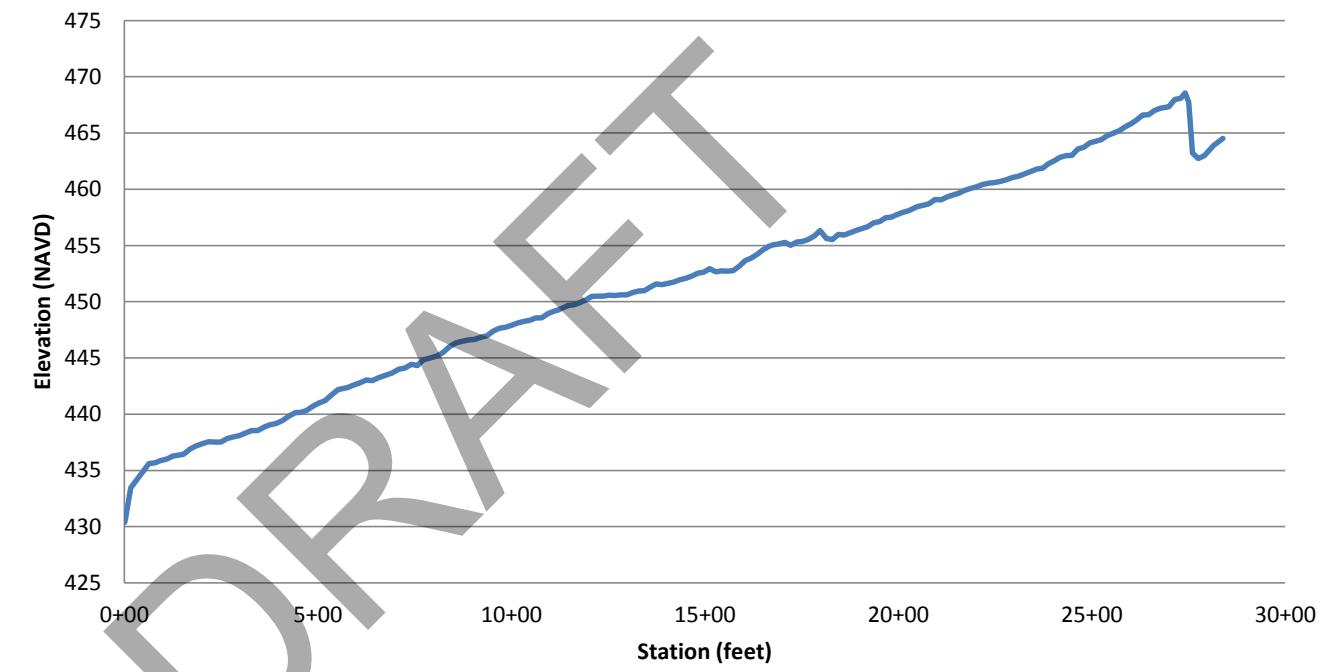
## **Neadham Road Levee**

**Puyallup River**

<b>Min</b>	430.34
<b>Max</b>	468.55

<b>Station Begin</b>	0+00
<b>Station End</b>	28+39

### **Levee Profile**



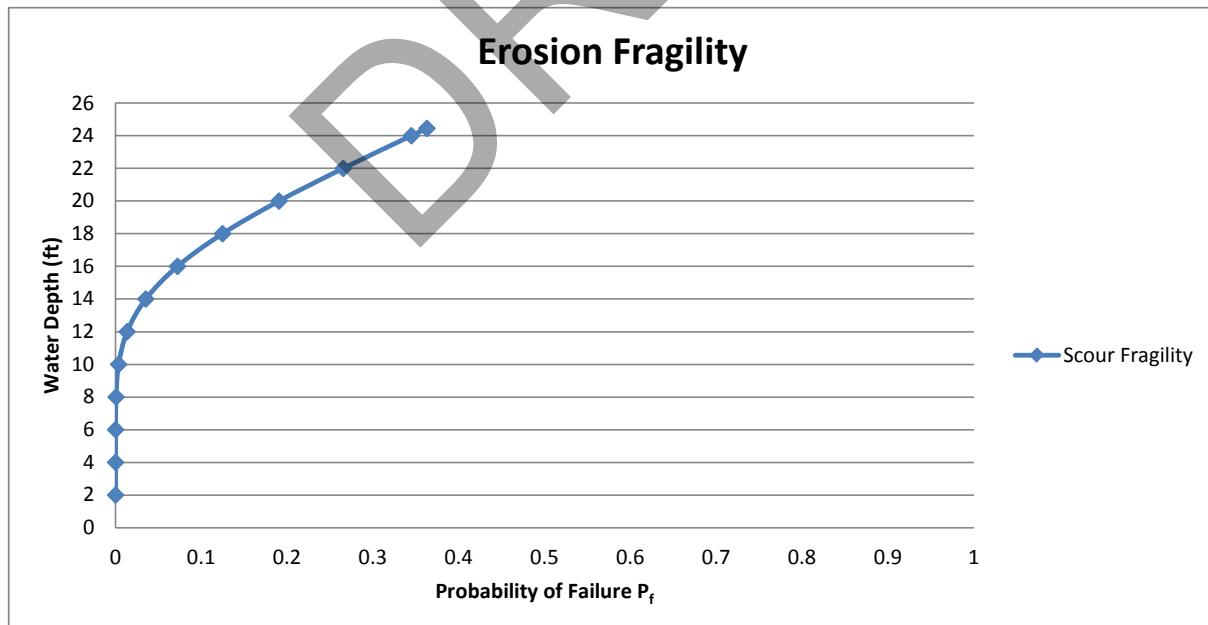
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### North Levee Road Levee

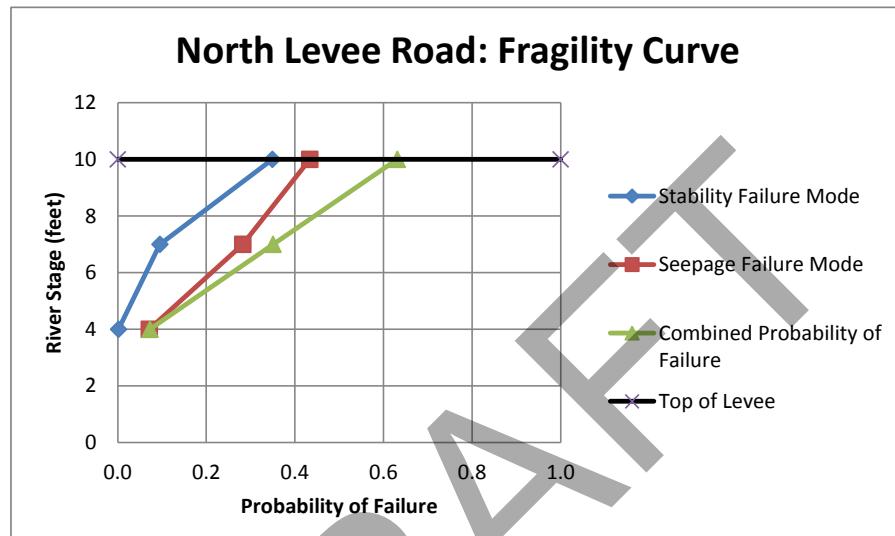
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.00062	CV(s) =	0.1	0.00062
Manning's "n"	n =	0.035	CV(n) =	0.15	0.00525
Scouring Velocity	$V_{crit} =$	9.74	$CV(V_{crit})$	0.2	1.95

Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	1.678	0.1581139		-1.758564983	0.254950976	-6.89766	2.6433E-12
4	2.664	0.1581139		-1.296466863	0.254950976	-5.08516	1.8366E-07
6	3.491	0.1581139		-1.02615679	0.254950976	-4.02492	2.8498E-05
8	4.229	0.1581139		-0.834368742	0.254950976	-3.27266	0.0005327
10	4.907	0.1581139		-0.685606375	0.254950976	-2.68917	0.0035815
12	5.541	0.1581139		-0.56405867	0.254950976	-2.21242	0.01346882
14	6.141	0.1581139		-0.46129155	0.254950976	-1.80933	0.03519954
16	6.713	0.1581139		-0.372270622	0.254950976	-1.46017	0.0721223
18	7.261	0.1581139		-0.293748598	0.254950976	-1.15218	0.12462422
20	7.789	0.1581139		-0.223508254	0.254950976	-0.87667	0.19033255
22	8.300	0.1581139		-0.159968134	0.254950976	-0.62745	0.26518325
24	8.796	0.1581139		-0.10196055	0.254950976	-0.39992	0.34460692
24.45	8.906	0.1581139		-0.089576293	0.254950976	-0.35135	0.36266397



<b>North Levee Road</b>
Fragility Curve
Cross Section from STA 57+80

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 10' +					
10	0.349	10	0.434	10	0.631
7	0.095	7	0.282	7	0.351
4	0.002	4	0.071	4	0.073



OVERTOPPING - 10' +	
Top of Levee	
10	0
10	1

Stability	TOL		TOL - 3'		TOL - 6'		Seepage
	Stability	Seepage	Stability	Seepage	Stability	Seepage	
MLV	1.25	0.63	1.50	0.45	1.70	0.25	MLV
Soil Unit 1	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.29	0.63	1.53	0.45	1.72	0.25
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.20	0.63	1.46	0.45	1.67	0.25
	log(K <sub>h</sub> )-1SD	0.61	0.52	1.00	0.37	1.42	0.21
	log(K <sub>h</sub> )+1SD	1.29	0.72	1.55	0.52	1.74	0.29
	γ -1SD	1.20	0.64	1.46	0.46	1.67	0.26
	γ +1SD	1.30	0.62	1.53	0.44	1.72	0.25
	φ -1SD	1.11	1.37	1.33	0.98	1.51	0.64
	φ +1SD	1.40	0.39	1.68	0.27	1.90	0.17
Soil Unit 2	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.24	0.39	1.48	0.27	1.68	0.64
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.25	1.37	1.50	0.98	1.69	0.17
	log(K <sub>h</sub> )-1SD	1.31	(i)	1.56	(i)	1.74	(i)
	log(K <sub>h</sub> )+1SD	0.65		1.02		1.43	
	γ -1SD	1.25		1.50		1.70	
	γ +1SD	1.25		1.50		1.70	
	φ -1SD	1.25		1.50		1.70	
	φ +1SD	1.25		1.50		1.70	

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	North Levee Road
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	North Levee Road cross section from STA 57+80. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-2	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-2	0	0	0	0	0	1.47	
2	52.6	1.5	1.5	-3	-2	0	0	0	0	0	1.34	
3	62.6	1.5	1.5	-3	-2	0	0	0	0	0	1.60	0.26
4	57.6	1	1.5	-3	-2	0	0	0	0	0	1.78	
5	57.6	2	1.5	-3	-2	0	0	0	0	0	1.28	-0.497
6	57.6	1.5	1	-3	-2	0	0	0	0	0	1.45	
7	57.6	1.5	2	-3	-2	0	0	0	0	0	1.49	0.03853
8	57.6	1.5	1.5	-4	-2	0	0	0	0	0	0.67	
9	57.6	1.5	1.5	-2	-2	0	0	0	0	0	2.36	1.68945
10	57.6	1.5	1.5	-3	-3	0	0	0	0	0	2.35	
11	57.6	1.5	1.5	-3	-1	0	0	0	0	0	0.67	-1.68101
12	57.6	1.5	1.5	-3	0	0	0	0	0	0		
13	57.6	1.5	1.5	-3	0	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-2	0	0	0	0	0		

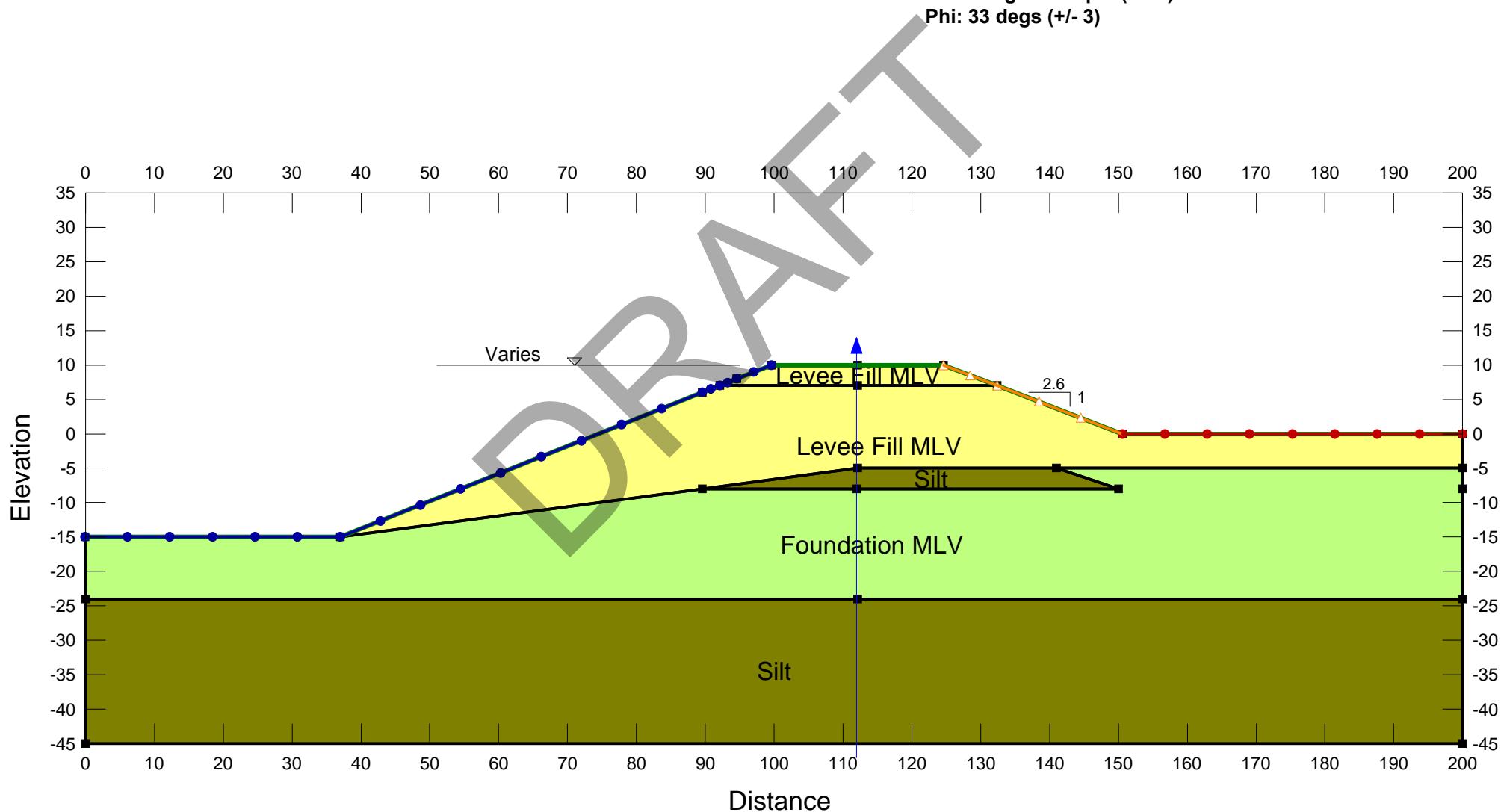
Standard deviation of F,	$\sigma_F$	1.224
Coefficient of variation of F,	$V_F$	0.833
Log normal reliability index,	$\beta_{LN}$	0.167
Reliability		0.566
Probability of failure		0.434

**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

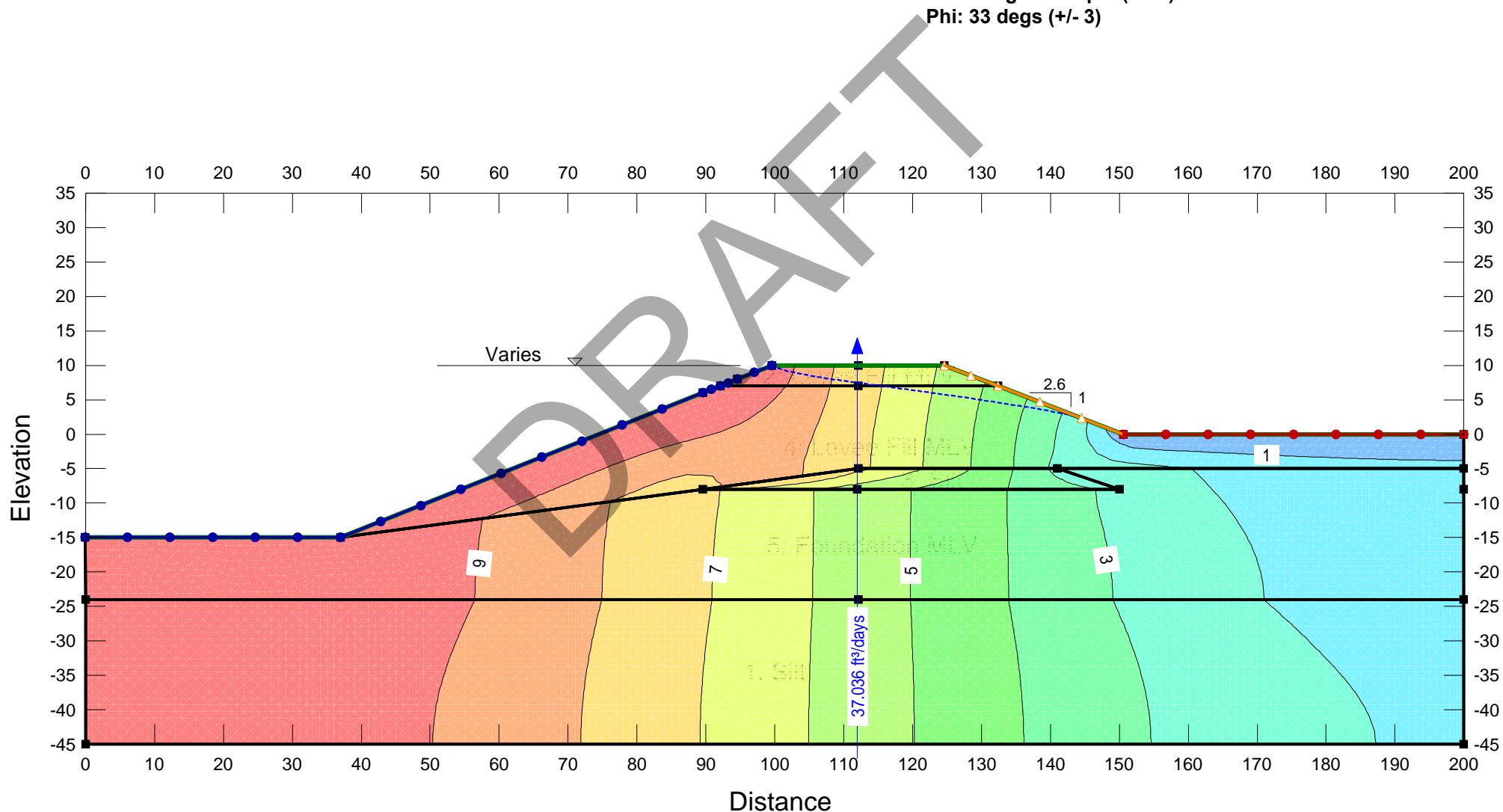


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

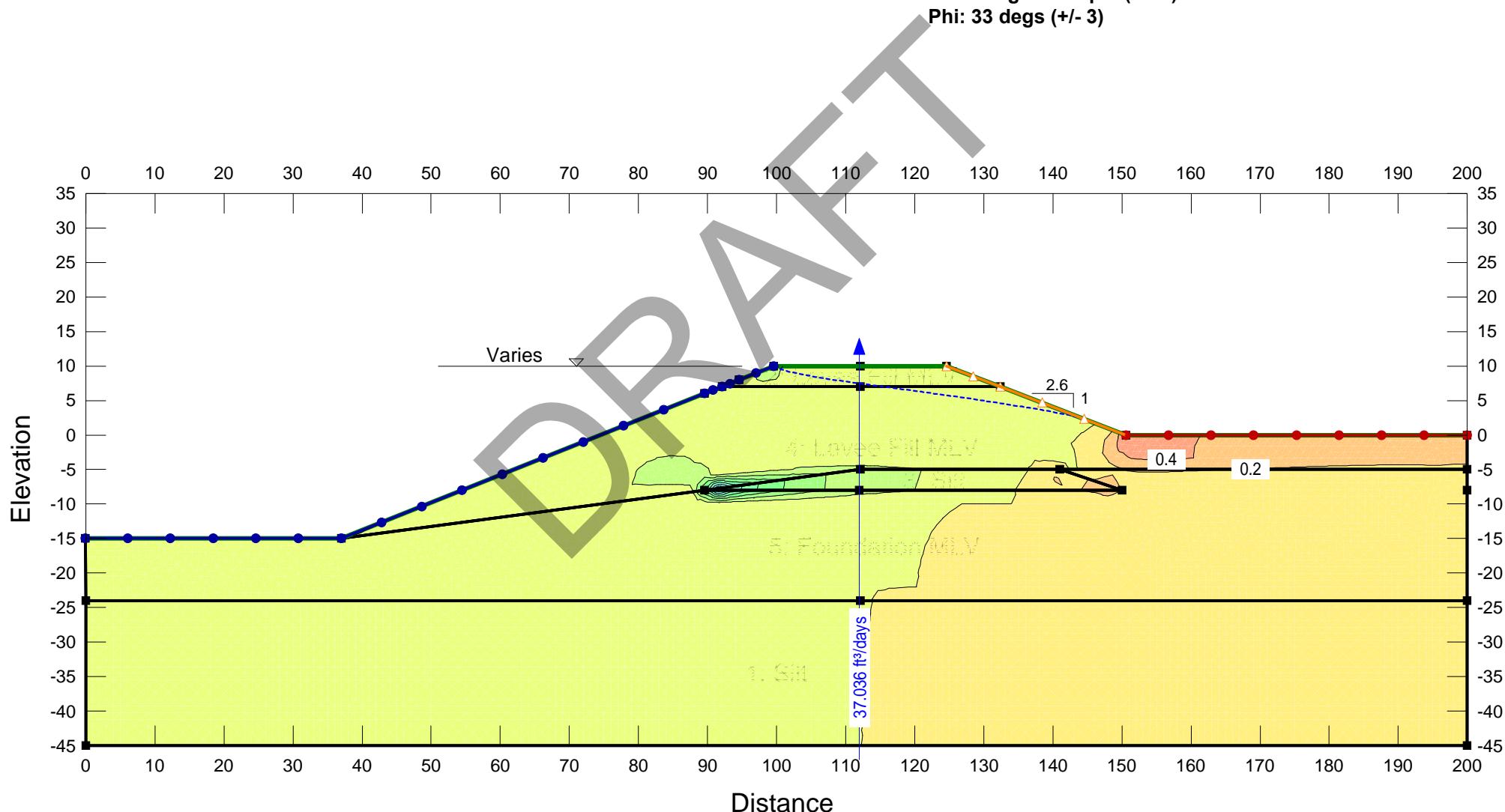


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 log(K-Sat): -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



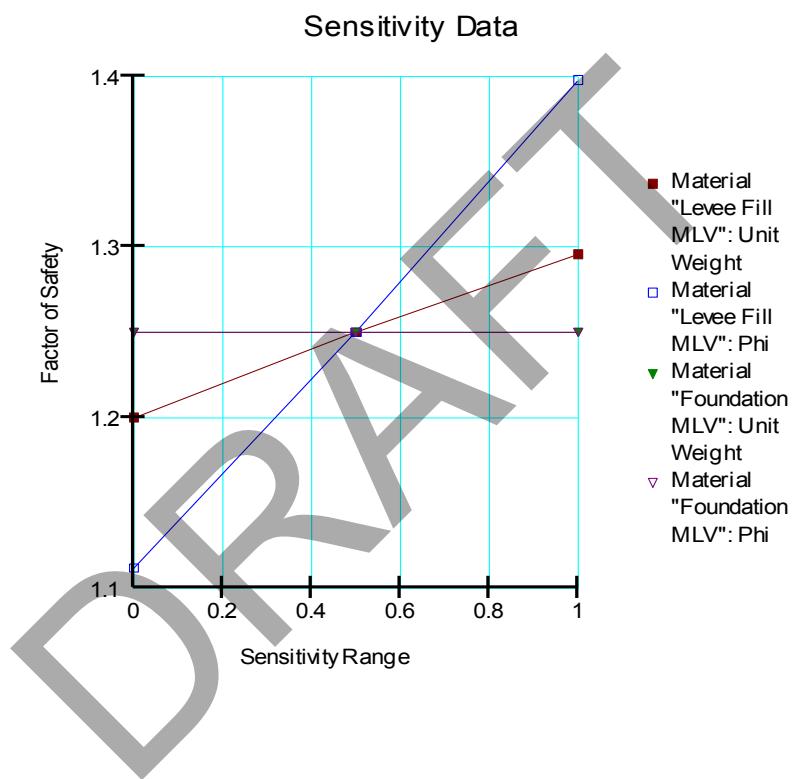
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	North Levee Road
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	North Levee Road cross section from STA 57+80. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-2	120	33	0	0	1.25	
2	1	-3	120	33	1.5	-2	120	33	0	0	1.29	
3	2	-3	120	33	1.5	-2	120	33	0	0	1.20	-0.09
4	1.5	-4	120	33	1.5	-2	120	33	0	0	0.61	
5	1.5	-2	120	33	1.5	-2	120	33	0	0	1.29	0.68
6	1.5	-3	115	33	1.5	-2	120	33	0	0	1.20	
7	1.5	-3	125	33	1.5	-2	120	33	0	0	1.30	0.09574
8	1.5	-3	120	30	1.5	-2	120	33	0	0	1.11	
9	1.5	-3	120	36	1.5	-2	120	33	0	0	1.40	0.28596
10	1.5	-3	120	33	1	-2	120	33	0	0	1.24	
11	1.5	-3	120	33	2	-2	120	33	0	0	1.25	0.01
12	1.5	-3	120	33	1.5	-3	120	33	0	0	1.31	
13	1.5	-3	120	33	1.5	-1	120	33	0	0	0.65	-0.66
14	1.5	-3	120	33	1.5	-2	115	33	0	0	1.25	
15	1.5	-3	120	33	1.5	-2	125	33	0	0	1.25	0
16	1.5	-3	120	33	1.5	-2	120	30	0	0	1.25	
17	1.5	-3	120	33	1.5	-2	120	36	0	0	1.25	0
18	1.5	-3	120	33	1.5	-2	120	33	0	0		
19	1.5	-3	120	33	1.5	-2	120	33	0	0		0
20	1.5	-3	120	33	1.5	-2	120	33	0	0		
21	1.5	-3	120	33	1.5	-2	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.499
Coefficient of variation of F,	$V_F$	0.399
Log normal reliability index,	$\beta_{LN}$	0.388
Reliability		0.651
Probability of failure		0.349

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.2000642	1.1118824	1.2501215	1.2501215
0.5	1.2501215	1.2501215	1.2501215	1.2501215
1	1.2958035	1.3978444	1.2501215	1.2501215

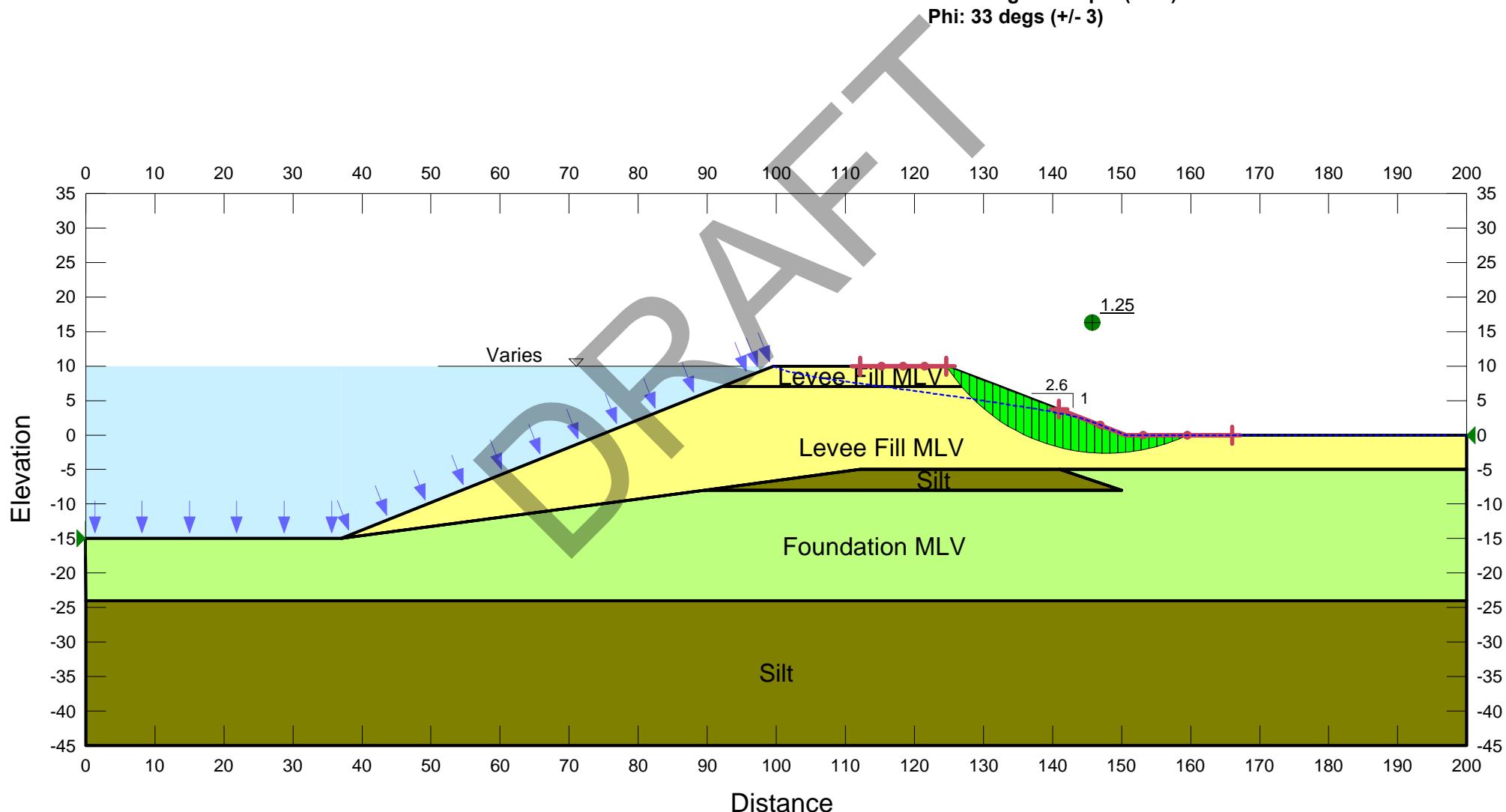


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	North Levee Road
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	North Levee Road Levee cross section from STA 57+80. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-2	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-2	0	0	0	0	0	2.05	
2	52.6	1.5	1.5	-3	-2	0	0	0	0	0	1.87	
3	62.6	1.5	1.5	-3	-2	0	0	0	0	0	2.23	0.35613
4	57.6	1	1.5	-3	-2	0	0	0	0	0	2.49	
5	57.6	2	1.5	-3	-2	0	0	0	0	0	1.77	-0.72204
6	57.6	1.5	1	-3	-2	0	0	0	0	0	2.02	
7	57.6	1.5	2	-3	-2	0	0	0	0	0	2.08	0.05683
8	57.6	1.5	1.5	-4	-2	0	0	0	0	0	0.94	
9	57.6	1.5	1.5	-2	-2	0	0	0	0	0	3.41	2.46931
10	57.6	1.5	1.5	-3	-3	0	0	0	0	0	3.42	
11	57.6	1.5	1.5	-3	-1	0	0	0	0	0	0.94	-2.47689
12	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-2	0	0	0	0	0		

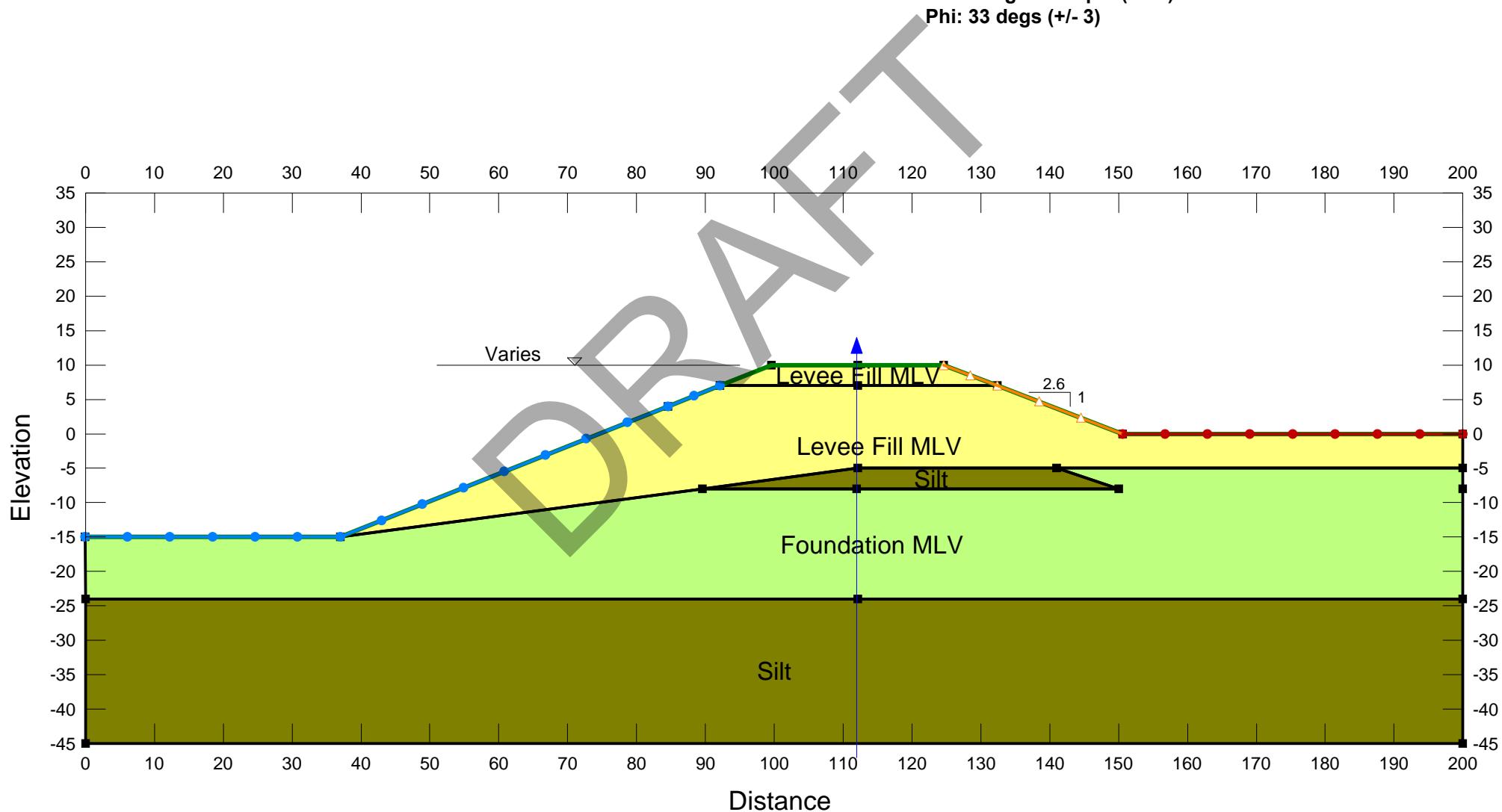
Standard deviation of F,	$\sigma_F$	1.795
Coefficient of variation of F,	$V_F$	0.875
Log normal reliability index,	$\beta_{LN}$	0.576
Reliability		0.718
Probability of failure		0.282

**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

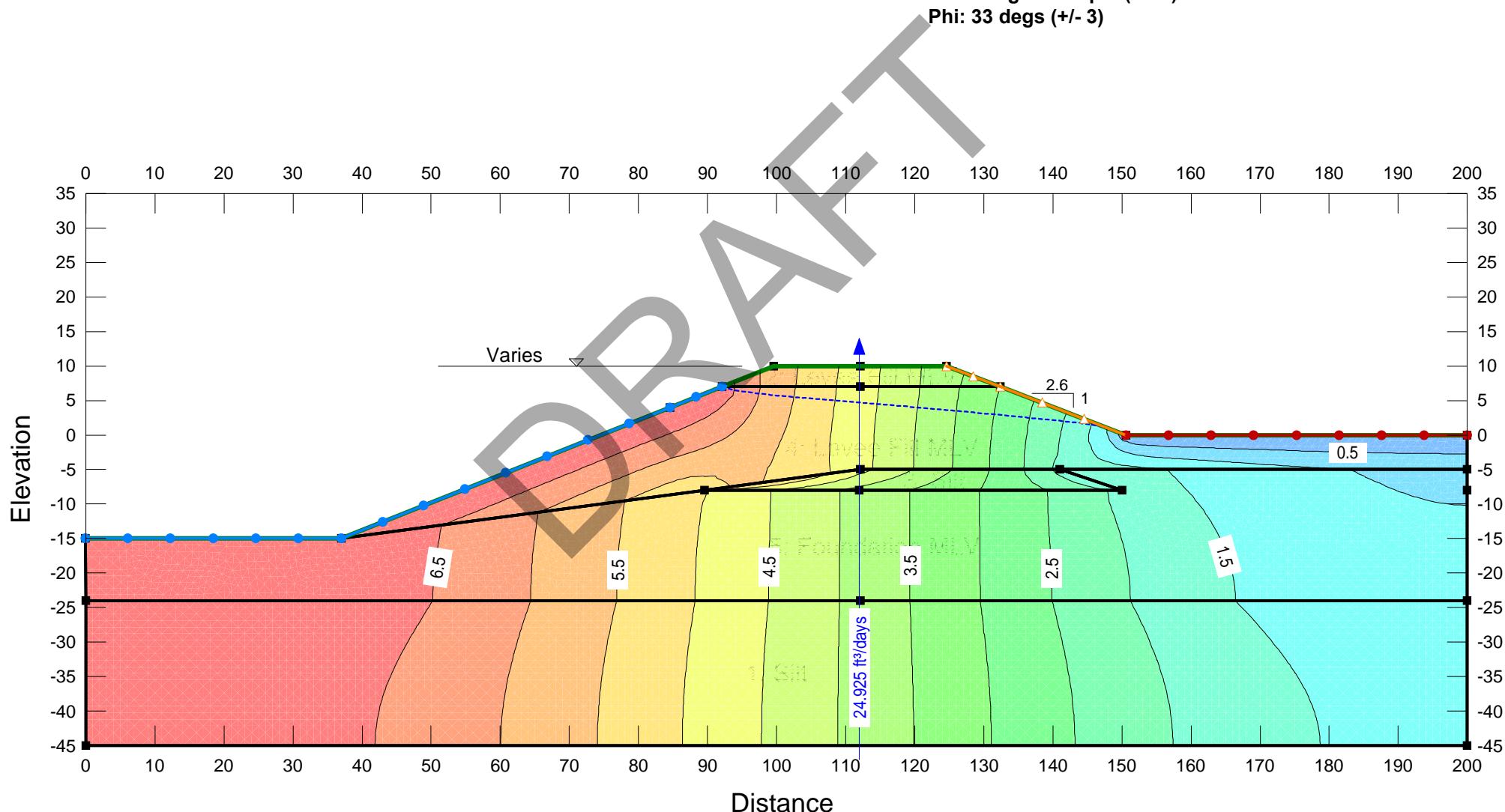


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
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 Unit Weight: 120 pcf (+/- 5)  
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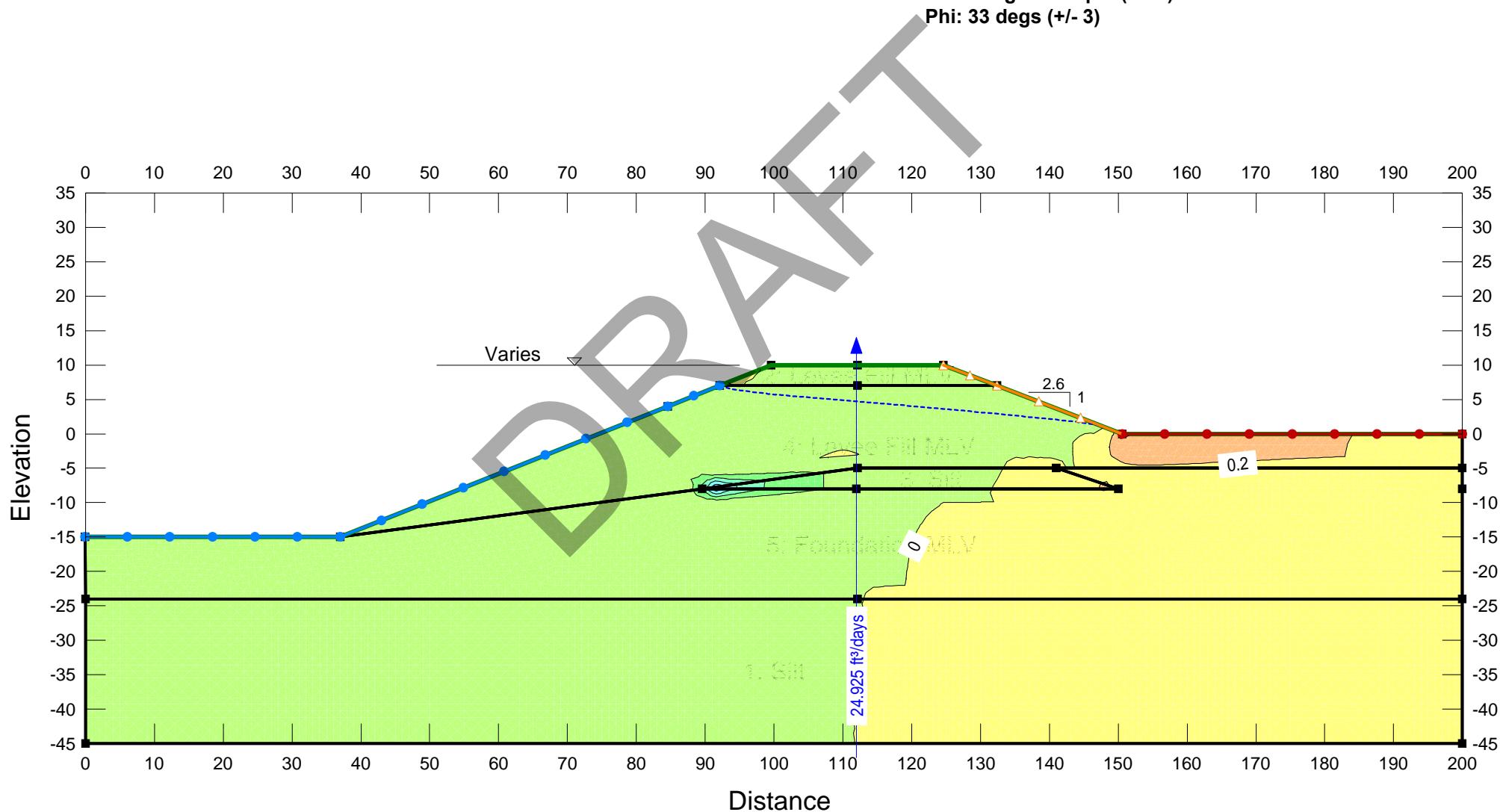


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
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**Silt**  
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**Levee Foundation (SP)**  
 log(K-Sat): -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



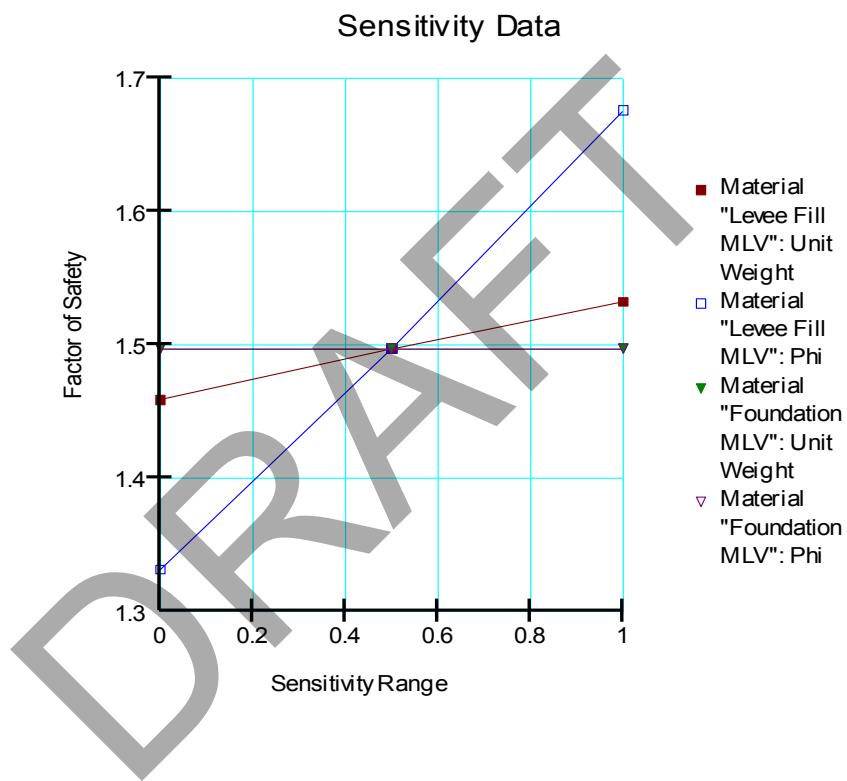
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	North Levee Road
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	North Levee Road Levee cross section from STA 57+80. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-2	120	33	0	0	1.50	
2	1	-3	120	33	1.5	-2	120	33	0	0	1.53	
3	2	-3	120	33	1.5	-2	120	33	0	0	1.46	-0.07
4	1.5	-4	120	33	1.5	-2	120	33	0	0	1.00	
5	1.5	-2	120	33	1.5	-2	120	33	0	0	1.55	0.55
6	1.5	-3	115	33	1.5	-2	120	33	0	0	1.46	
7	1.5	-3	125	33	1.5	-2	120	33	0	0	1.53	0.07359
8	1.5	-3	120	30	1.5	-2	120	33	0	0	1.33	
9	1.5	-3	120	36	1.5	-2	120	33	0	0	1.68	0.3444
10	1.5	-3	120	33	1	-2	120	33	0	0	1.48	
11	1.5	-3	120	33	2	-2	120	33	0	0	1.50	0.02
12	1.5	-3	120	33	1.5	-3	120	33	0	0	1.56	
13	1.5	-3	120	33	1.5	-1	120	33	0	0	1.02	-0.54
14	1.5	-3	120	33	1.5	-2	115	33	0	0	1.50	
15	1.5	-3	120	33	1.5	-2	125	33	0	0	1.50	0
16	1.5	-3	120	33	1.5	-2	120	30	0	0	1.50	
17	1.5	-3	120	33	1.5	-2	120	36	0	0	1.50	0
18	1.5	-3	120	33	1.5	-2	120	33	0	0		
19	1.5	-3	120	33	1.5	-2	120	33	0	0		0
20	1.5	-3	120	33	1.5	-2	120	33	0	0		
21	1.5	-3	120	33	1.5	-2	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.425
Coefficient of variation of F,	$V_F$	0.284
Log normal reliability index,	$\beta_{LN}$	1.310
Reliability		0.905
Probability of failure		0.095

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.4588143	1.3315035	1.4972472	1.4972472
0.5	1.4972472	1.4972472	1.4972472	1.4972472
1	1.5324092	1.6759056	1.4972472	1.4972472

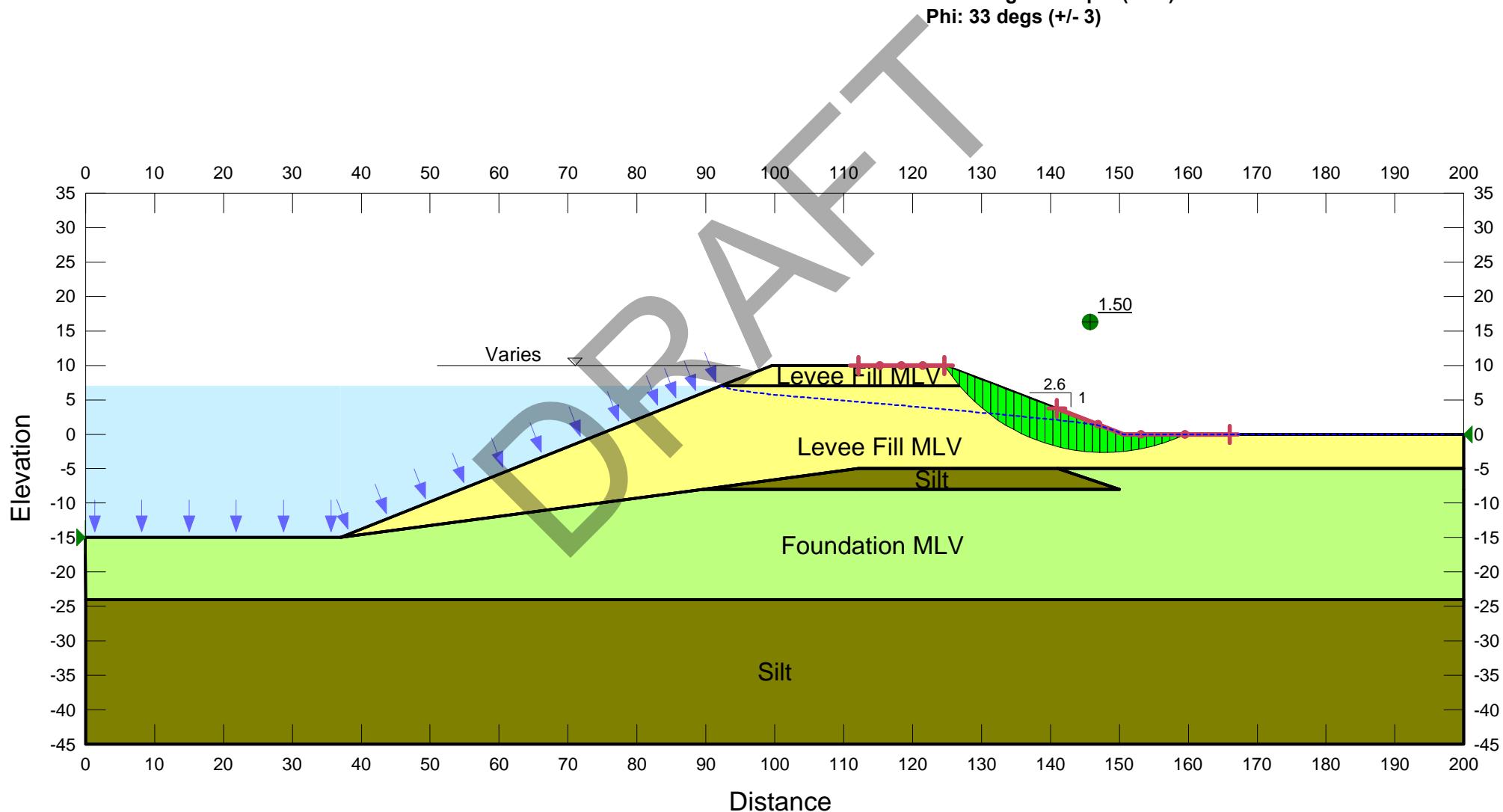


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	North Levee Road
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	North Levee Road Levee cross section from STA 57+80. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-2	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-2	0	0	0	0	0	3.63	
2	52.6	1.5	1.5	-3	-2	0	0	0	0	0	3.31	
3	62.6	1.5	1.5	-3	-2	0	0	0	0	0	3.94	0.63019
4	57.6	1	1.5	-3	-2	0	0	0	0	0	4.43	
5	57.6	2	1.5	-3	-2	0	0	0	0	0	3.14	-1.28218
6	57.6	1.5	1	-3	-2	0	0	0	0	0	3.57	
7	57.6	1.5	2	-3	-2	0	0	0	0	0	3.68	0.1111
8	57.6	1.5	1.5	-4	-2	0	0	0	0	0	1.44	
9	57.6	1.5	1.5	-2	-2	0	0	0	0	0	5.48	4.0424
10	57.6	1.5	1.5	-3	-3	0	0	0	0	0	1.44	
11	57.6	1.5	1.5	-3	-1	0	0	0	0	0	5.43	3.98756
12	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-2	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-2	0	0	0	0	0		

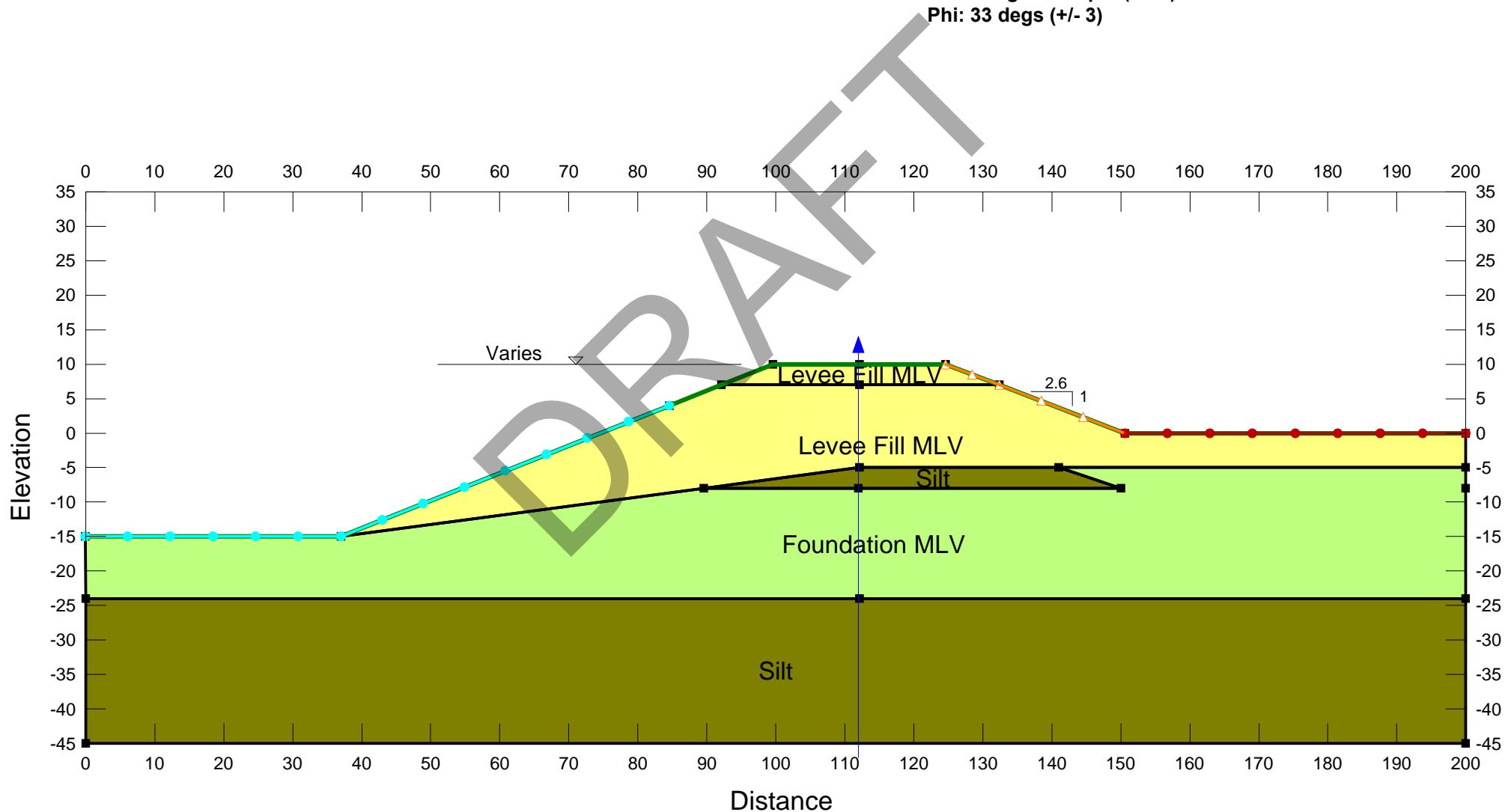
Standard deviation of F,	$\sigma_F$	2.928
Coefficient of variation of F,	$V_F$	0.807
Log normal reliability index,	$\beta_{LN}$	1.467
Reliability		0.929
Probability of failure		0.071

**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

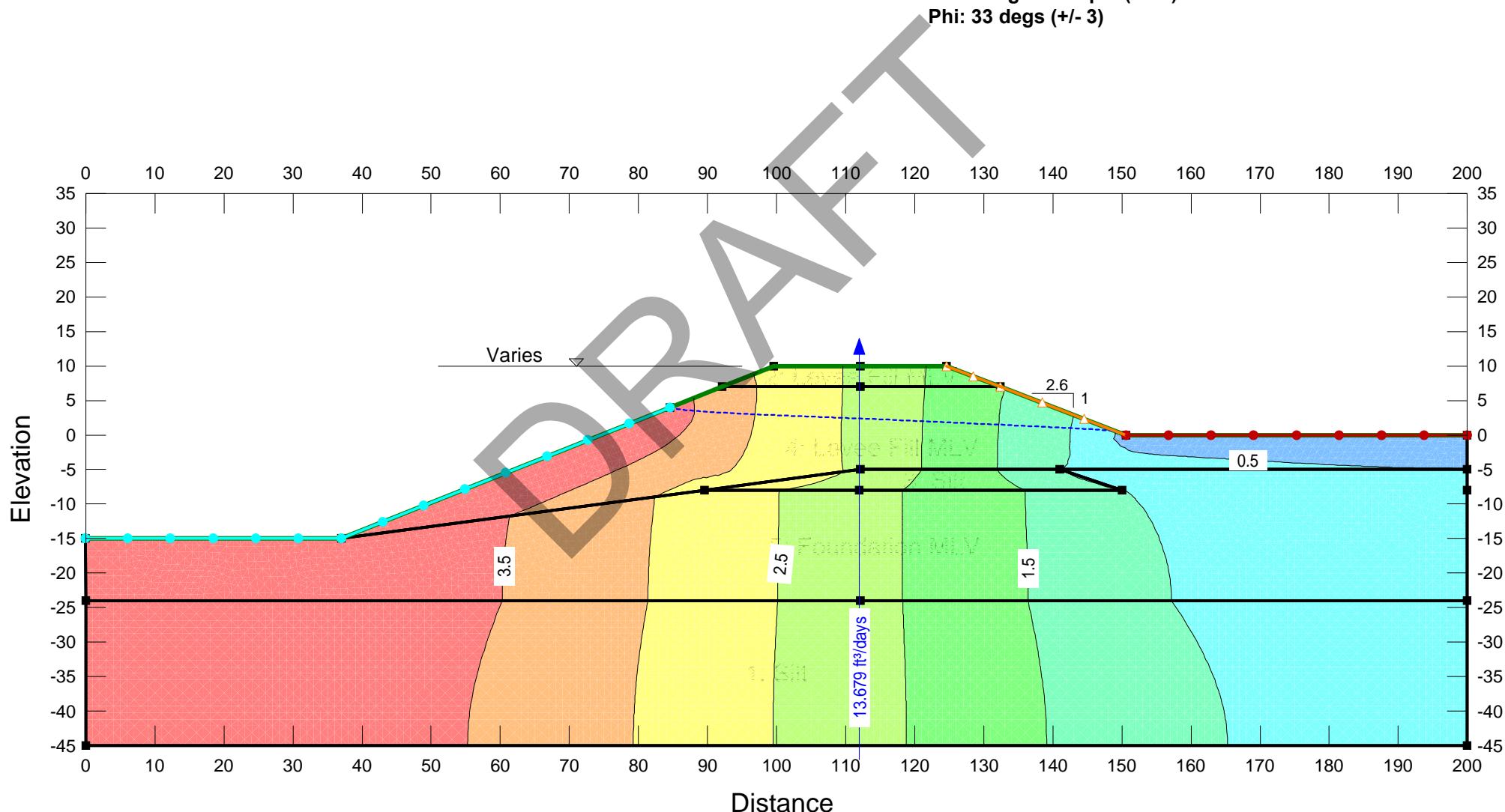


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

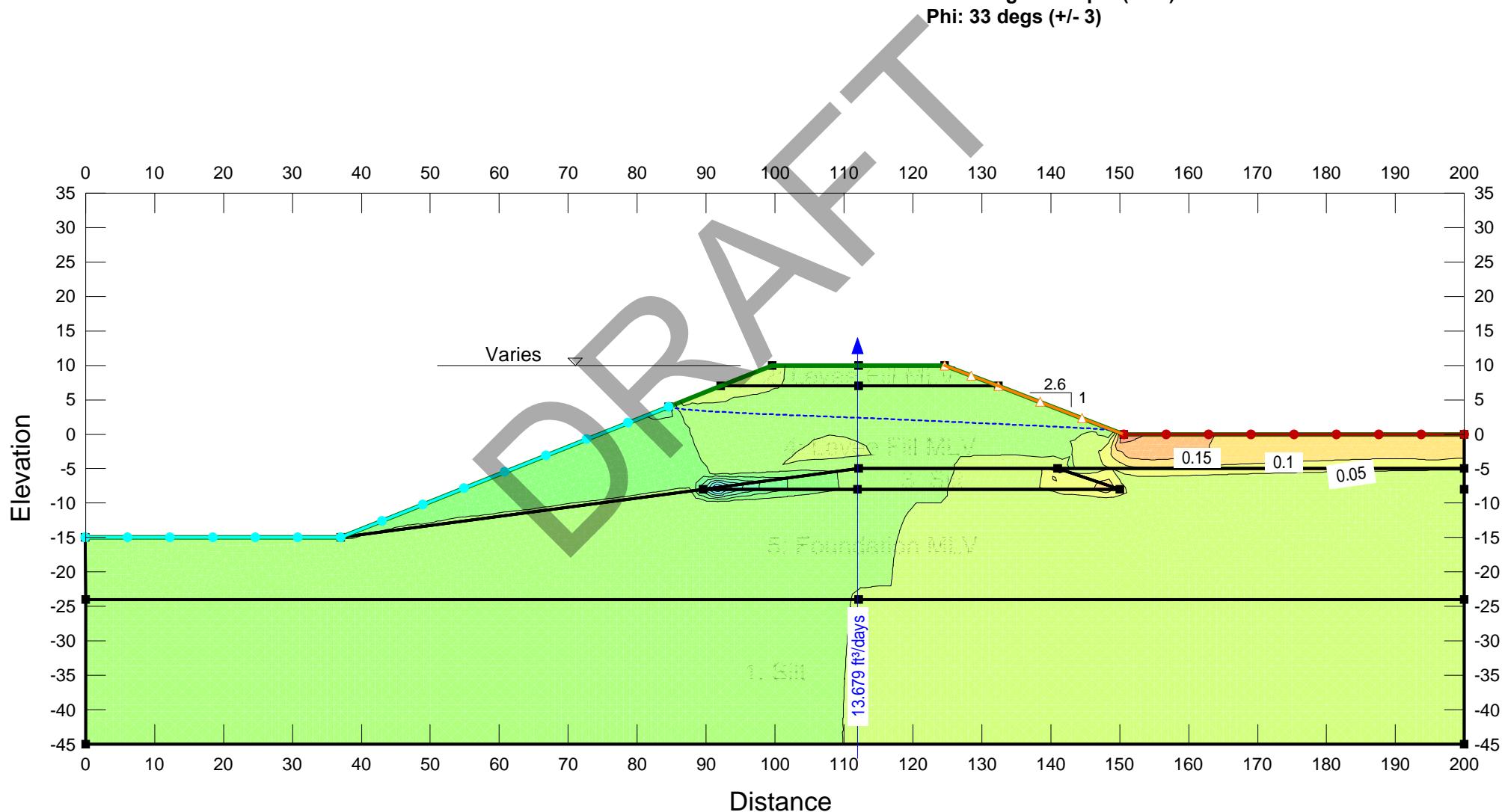


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
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**Levee Foundation (SP)**  
 log(K-Sat): -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



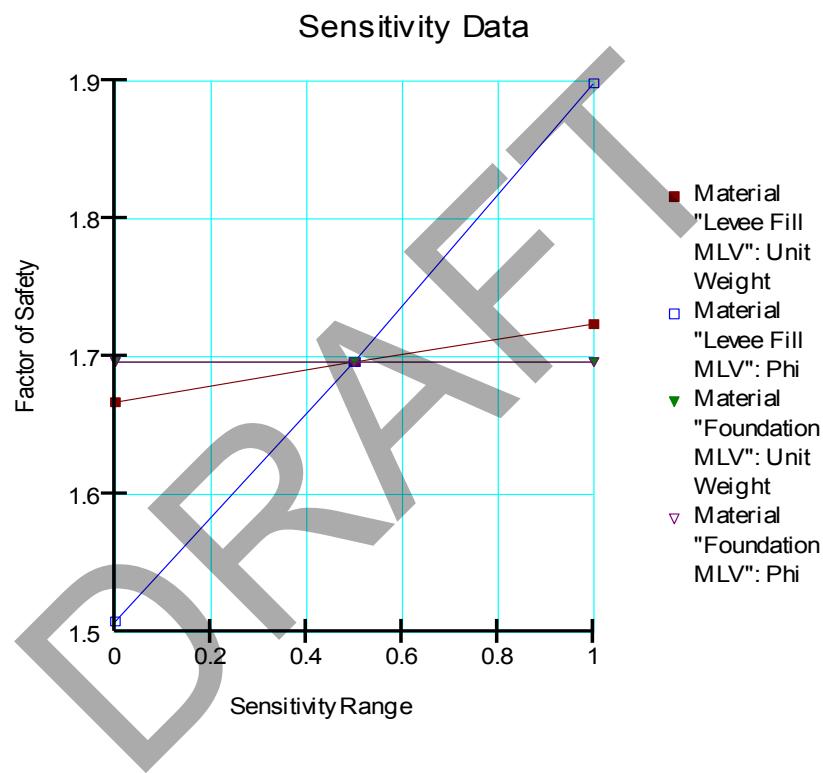
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	North Levee Road
Date	7-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	North Levee Road Levee cross section from STA 57+80. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-2	120	33	0	0	1.70	
2	1	-3	120	33	1.5	-2	120	33	0	0	1.72	
3	2	-3	120	33	1.5	-2	120	33	0	0	1.67	-0.05
4	1.5	-4	120	33	1.5	-2	120	33	0	0	1.42	
5	1.5	-2	120	33	1.5	-2	120	33	0	0	1.74	0.32
6	1.5	-3	115	33	1.5	-2	120	33	0	0	1.67	
7	1.5	-3	125	33	1.5	-2	120	33	0	0	1.72	0.05665
8	1.5	-3	120	30	1.5	-2	120	33	0	0	1.51	
9	1.5	-3	120	36	1.5	-2	120	33	0	0	1.90	0.39022
10	1.5	-3	120	33	1	-2	120	33	0	0	1.68	
11	1.5	-3	120	33	2	-2	120	33	0	0	1.69	0.01
12	1.5	-3	120	33	1.5	-3	120	33	0	0	1.74	
13	1.5	-3	120	33	1.5	-1	120	33	0	0	1.43	-0.31
14	1.5	-3	120	33	1.5	-2	115	33	0	0	1.70	
15	1.5	-3	120	33	1.5	-2	125	33	0	0	1.70	0
16	1.5	-3	120	33	1.5	-2	120	30	0	0	1.70	
17	1.5	-3	120	33	1.5	-2	120	36	0	0	1.70	0
18	1.5	-3	120	33	1.5	-2	120	33	0	0		
19	1.5	-3	120	33	1.5	-2	120	33	0	0		0
20	1.5	-3	120	33	1.5	-2	120	33	0	0		
21	1.5	-3	120	33	1.5	-2	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.299
Coefficient of variation of F,	$V_F$	0.176
Log normal reliability index,	$\beta_{LN}$	2.937
Reliability		0.998
Probability of failure		0.002

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.6668953	1.5081185	1.6960088	1.6960088
0.5	1.6960088	1.6960088	1.6960088	1.6960088
1	1.7235436	1.8983367	1.6960088	1.6960088

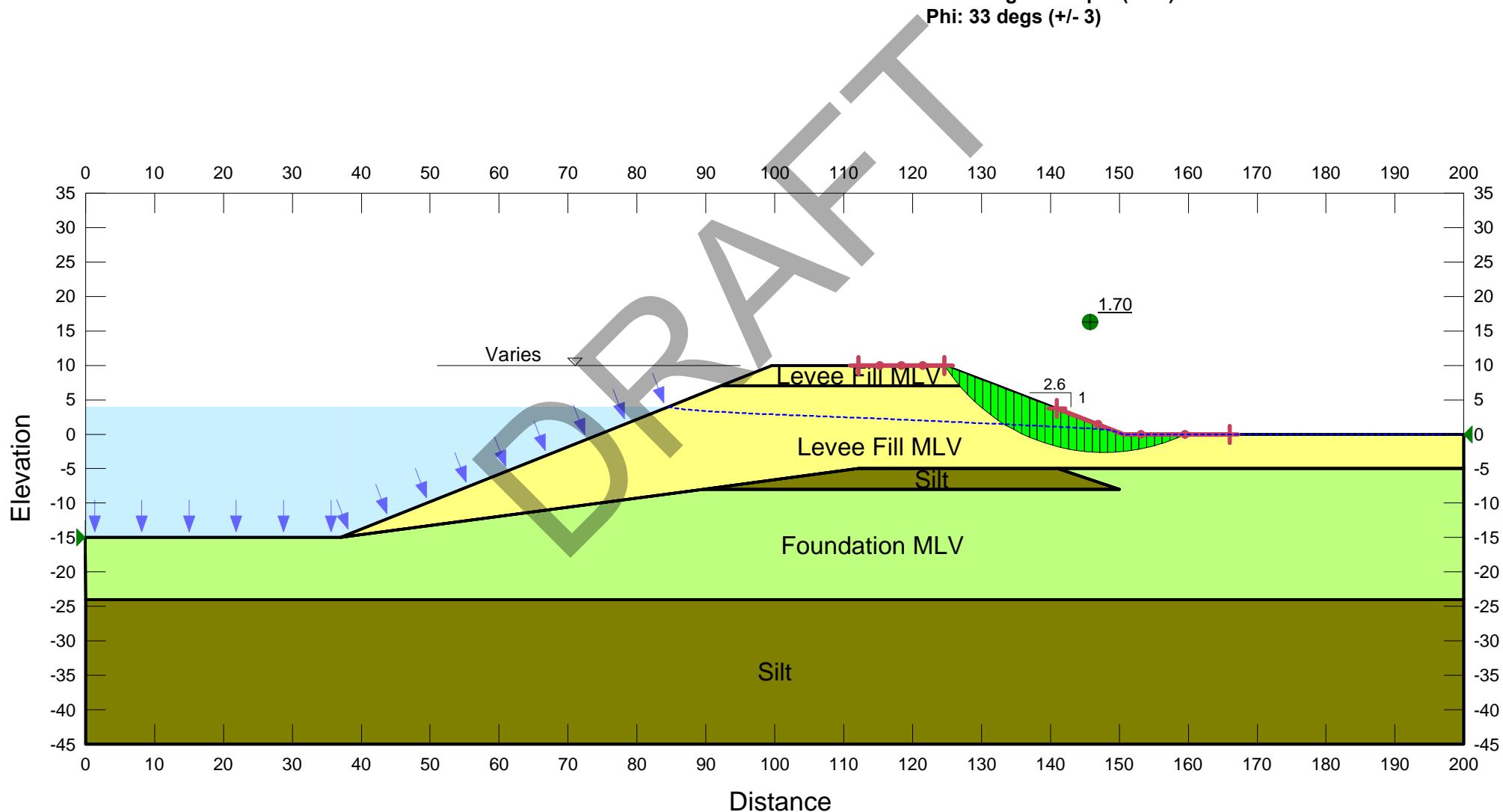


**North Levee Road Levee**  
**Puyallup River**  
**STA 57+80**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 110 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (SP)**  
 $\log(K\text{-Sat})$ : -2 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

*Old Cannery Cross Section Model & Erosion Analysis*

#### General Information

Location:	Pierce County, Washington
River:	Puyallup River
Levee Segment Name:	Old Cannery
Station:	22+87

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Only vegetation maintenance issues were noted.

#### Levee Geometry

Crown Width (W)	18 Feet
Landward Levee Height (H)	8 Feet
Riverward Slope (R)	2.1 H:1V
Landward Slope (L)	1.9 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	8 Feet
Breach Width at Top of Levee	179 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.56 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation material is unknown. Assumed typical silty SAND (SM) values.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
	Loose / Soft	Low
X	Medium	X Medium
	Dense / Stiff	High

**Remarks:** Levee embankment material is unknown. Assumed typical silty SAND with gravel (SP-SM) values.

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
---------

\*Expert Elicitation

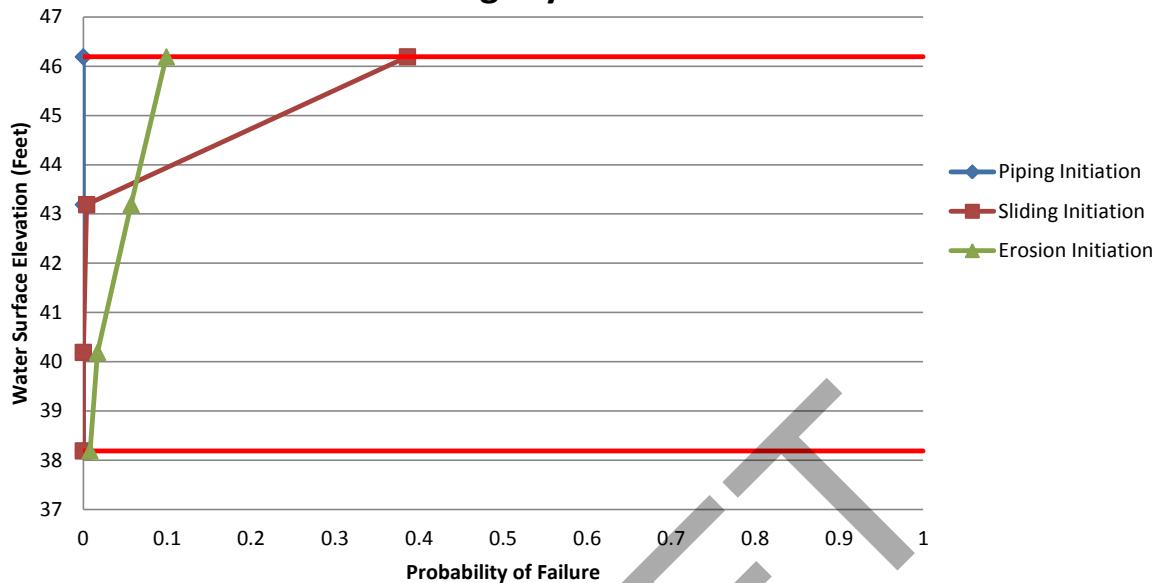
#### Final Fragility Curve

Elev.	Prob.
46.19	1.00
46.19	0.39
43.19	0.06
40.19	0.02
38.19	0.01

# PUYALLUP BASIN GENERAL INVESTIGATION

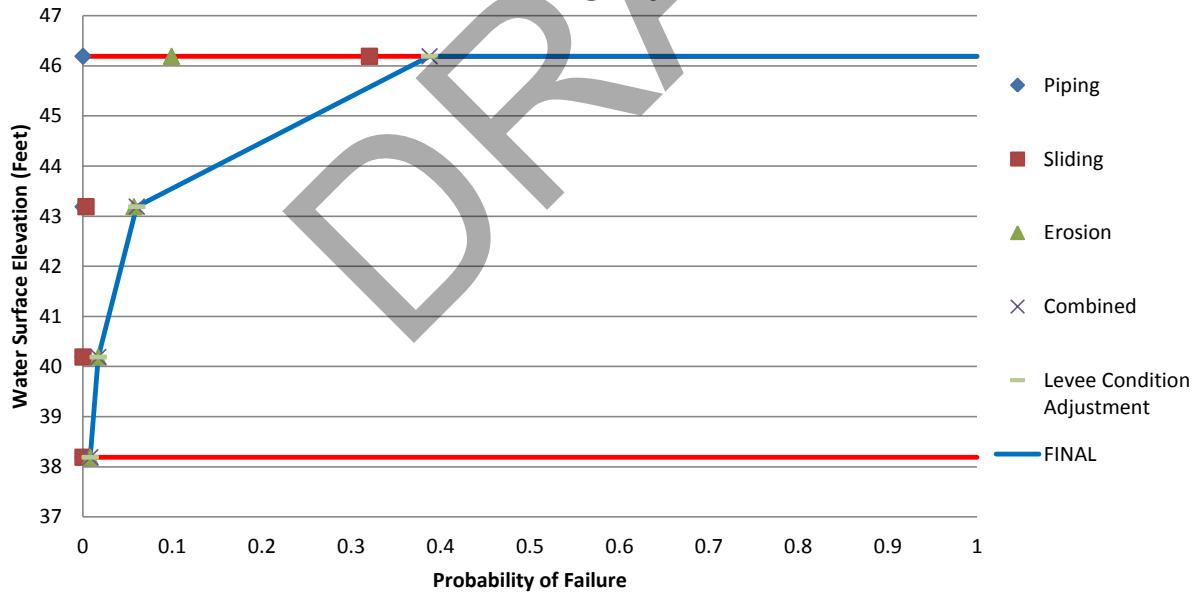
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



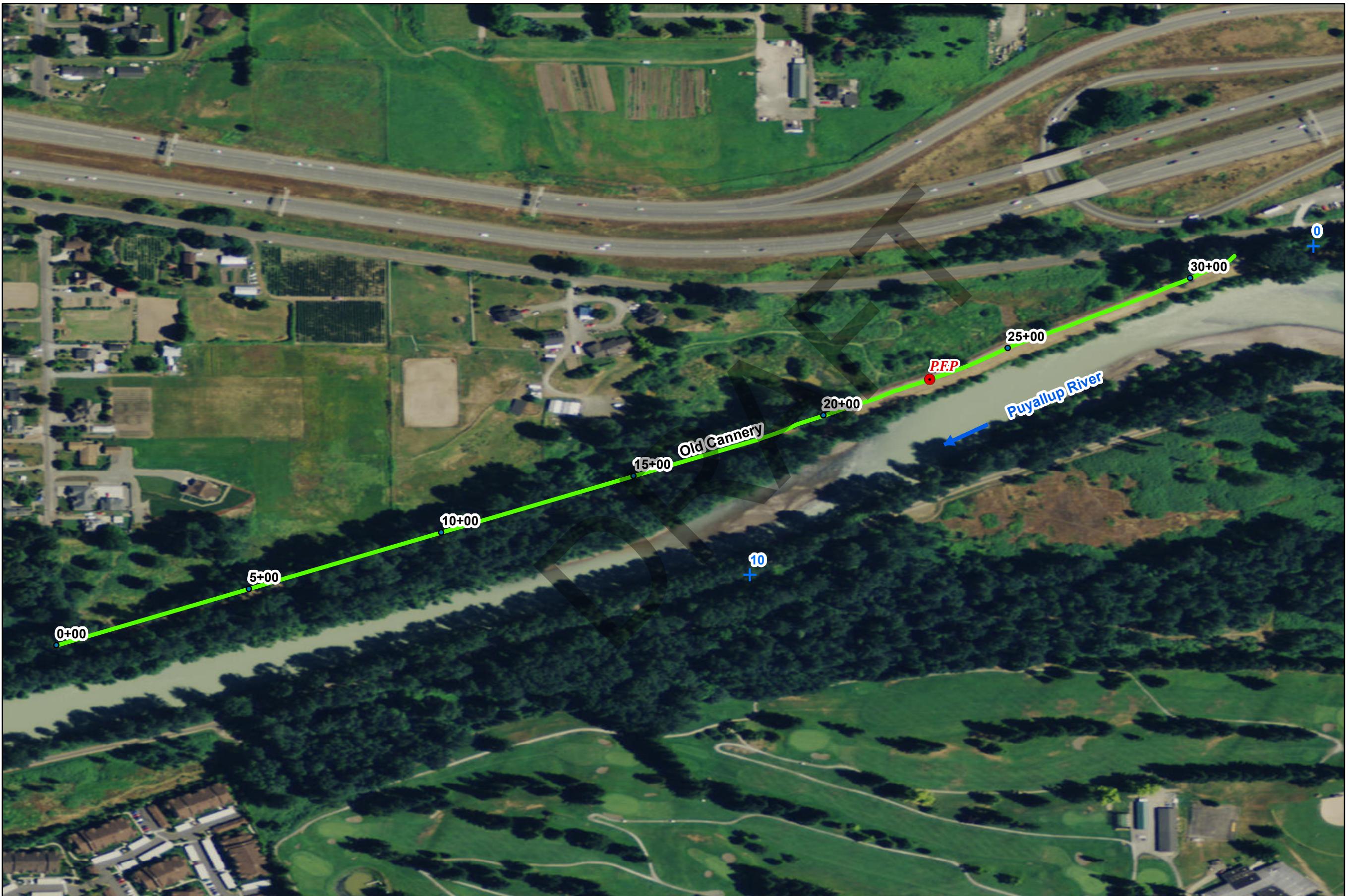
*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Old Cannery Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# Old Cannery Levee - Puyallup River



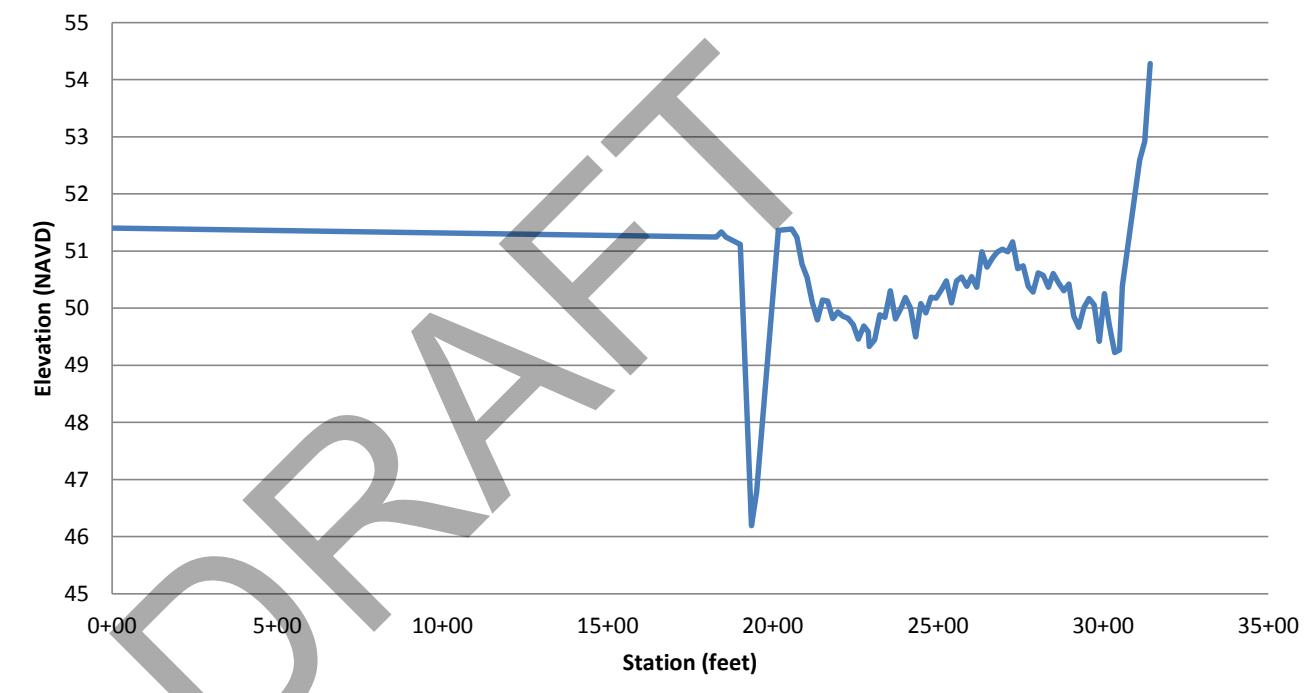
**Old Cannery Levee**

**Puyallup River**

<b>Min</b>	46.19
<b>Max</b>	54.28

<b>Station Begin</b>	0+00
<b>Station End</b>	31+43

**Levee Profile**



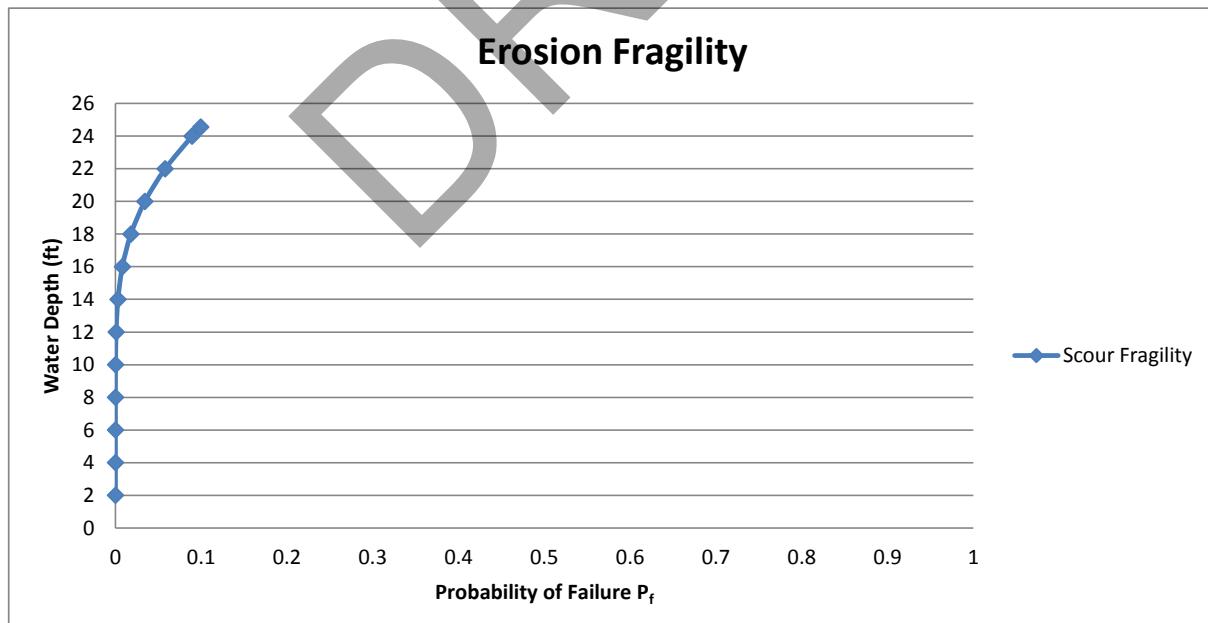
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Old Cannery Levee

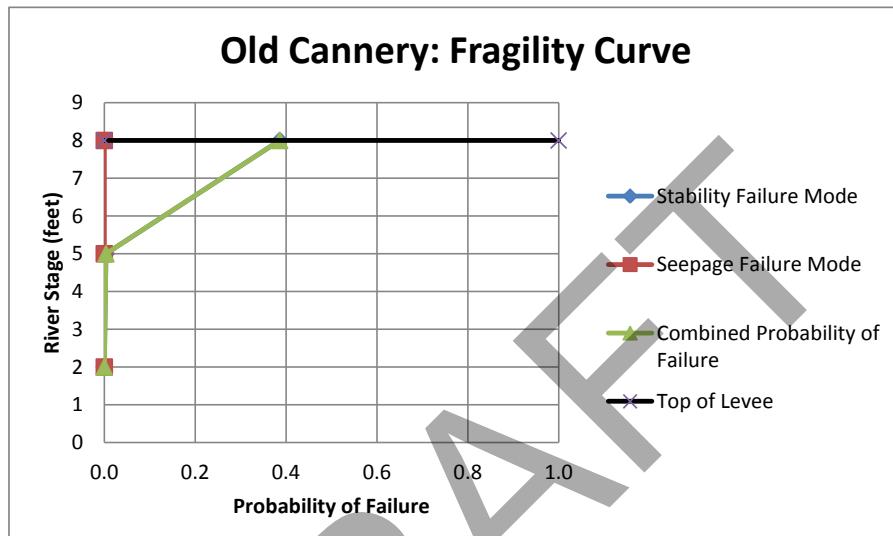
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.001	CV(s) =	0.1	0.0001
Manning's "n"	n =	0.04	CV(n) =	0.15	0.006
Scouring Velocity	$V_{crit} =$	13.77	$CV(V_{crit})$	0.2	2.75

Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	1.865	0.1581139		-1.999652065	0.254950976	-7.84328	2.1946E-15
4	2.960	0.1581139		-1.537553945	0.254950976	-6.03078	8.1584E-10
6	3.879	0.1581139		-1.267243873	0.254950976	-4.97054	3.3383E-07
8	4.699	0.1581139		-1.075455825	0.254950976	-4.21828	1.2308E-05
10	5.453	0.1581139		-0.926693457	0.254950976	-3.63479	0.0001391
12	6.158	0.1581139		-0.805145752	0.254950976	-3.15804	0.00079416
14	6.824	0.1581139		-0.702378633	0.254950976	-2.75496	0.002935
16	7.459	0.1581139		-0.613357704	0.254950976	-2.40579	0.00806884
18	8.069	0.1581139		-0.53483568	0.254950976	-2.0978	0.01796149
20	8.656	0.1581139		-0.464595337	0.254950976	-1.82229	0.03420528
22	9.224	0.1581139		-0.401055217	0.254950976	-1.57307	0.05785154
24	9.775	0.1581139		-0.343047632	0.254950976	-1.34554	0.08922489
24.56	9.926	0.1581139		-0.327670783	0.254950976	-1.28523	0.09935586



Old Cannery					
Fragility Curve					
Cross Section from STA 22+87					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 8' +					
8	0.386	8	2.0E-10	8	0.386
5	0.004	5	9.0E-13	5	0.004
2	1.1E-07	2	0.0E+00	2	0.000



OVERTOPPING -	8' +
Top of Levee	
8	0
8	1

Soil Unit	Stability	TOL		TOL - 3'		TOL - 6'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	1.07	0.34	1.34	0.15	1.54	0.07	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.06	0.34	1.34	0.15	1.54	0.07	γB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.08	0.34	1.35	0.15	1.54	0.07	γB +1SD
	log(K <sub>h</sub> )-1SD	1.18	0.34	1.39	0.16	1.54	0.07	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	0.96	0.34	1.26	0.14	1.52	0.07	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	γ -1SD	1.06	0.30	1.34	0.15	1.54	0.06	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	γ +1SD	1.08	0.38	1.34	0.20	1.53	0.08	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	φ -1SD	0.95	0.31	1.26	0.21	1.45	0.07	log(K <sub>h</sub> )-1SD
2	φ +1SD	1.14	0.33	1.43	0.15	1.64	0.08	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.11	0.33	1.37	0.22	1.55	0.08	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.05	0.31	1.33	0.16	1.53	0.07	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	0.96	(i)	1.26	(i)	1.52	(i)	
	log(K <sub>h</sub> )+1SD	1.18		1.39		1.54		
	γ -1SD	1.05		1.32		1.52		
	γ +1SD	1.09		1.36		1.56		
	γ -1SD	1.02		1.28		1.46		
	γ +1SD	1.13		1.41		1.62		

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Old Cannery
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Old Cannery Levee cross section from STA 22+87. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-3	0	0	0	0	0	2.71	
2	52.6	1.5	1.5	-3	-3	0	0	0	0	0	2.47	
3	62.6	1.5	1.5	-3	-3	0	0	0	0	0	2.94	0.47
4	57.6	1	1.5	-3	-3	0	0	0	0	0	2.71	
5	57.6	2	1.5	-3	-3	0	0	0	0	0	2.72	0.00956
6	57.6	1.5	1	-3	-3	0	0	0	0	0	3.10	
7	57.6	1.5	2	-3	-3	0	0	0	0	0	2.45	-0.64389
8	57.6	1.5	1.5	-4	-3	0	0	0	0	0	3.02	
9	57.6	1.5	1.5	-2	-3	0	0	0	0	0	2.80	-0.22136
10	57.6	1.5	1.5	-3	-4	0	0	0	0	0	2.80	
11	57.6	1.5	1.5	-3	-2	0	0	0	0	0	3.02	0.22235
12	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-3	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-3	0	0	0	0	0		

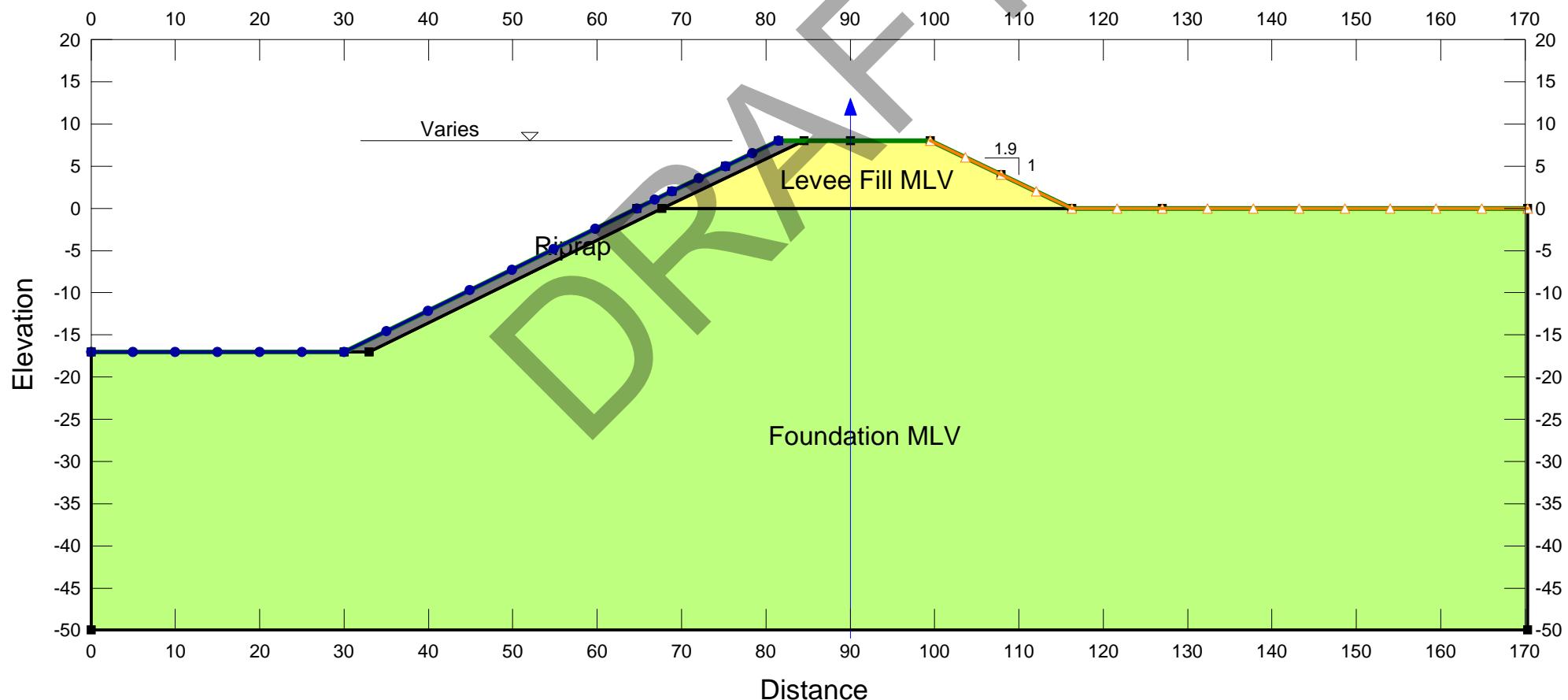
Standard deviation of F,	$\sigma_F$	0.428
Coefficient of variation of F,	$V_F$	0.158
Log normal reliability index,	$\beta_{LN}$	6.253
Reliability		1.000
Probability of failure		2.0E-10

**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

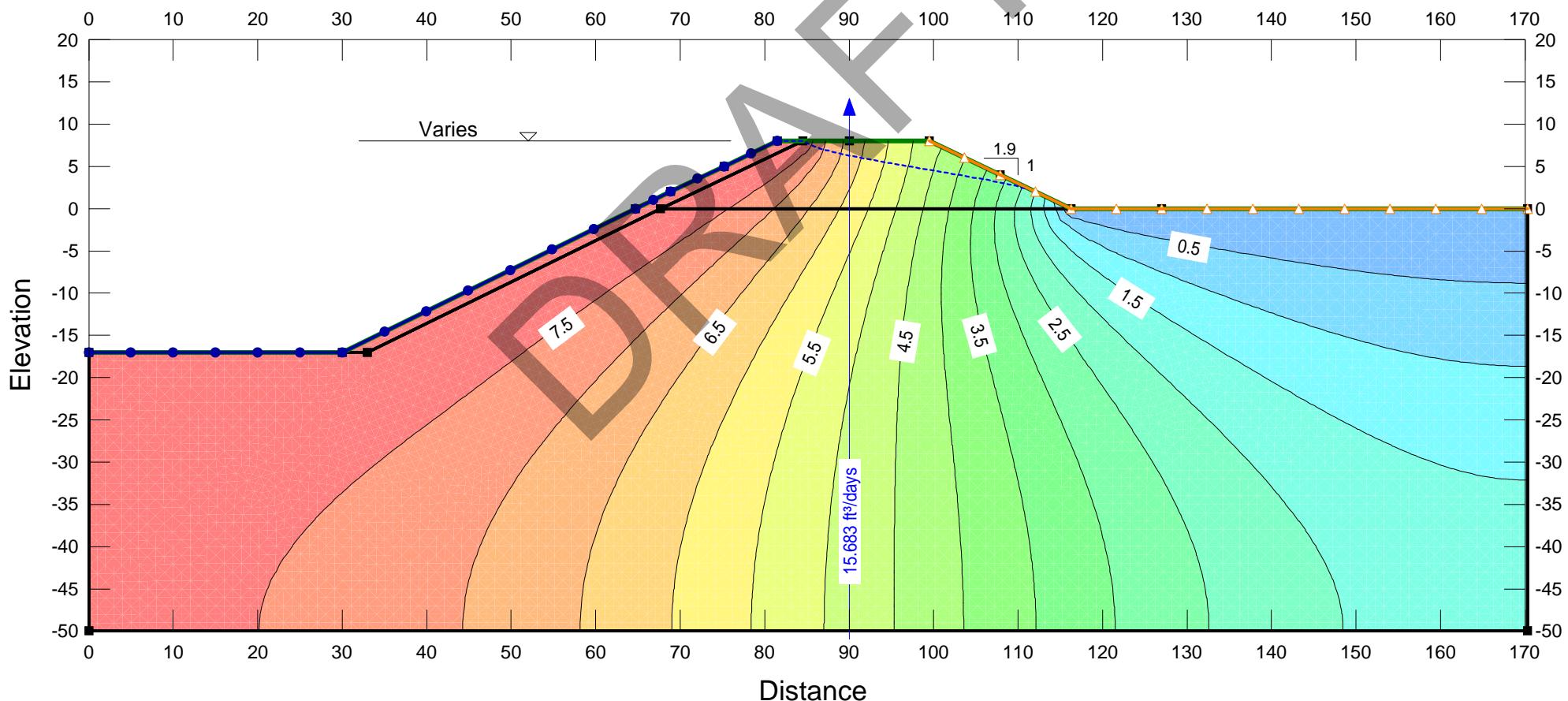


**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
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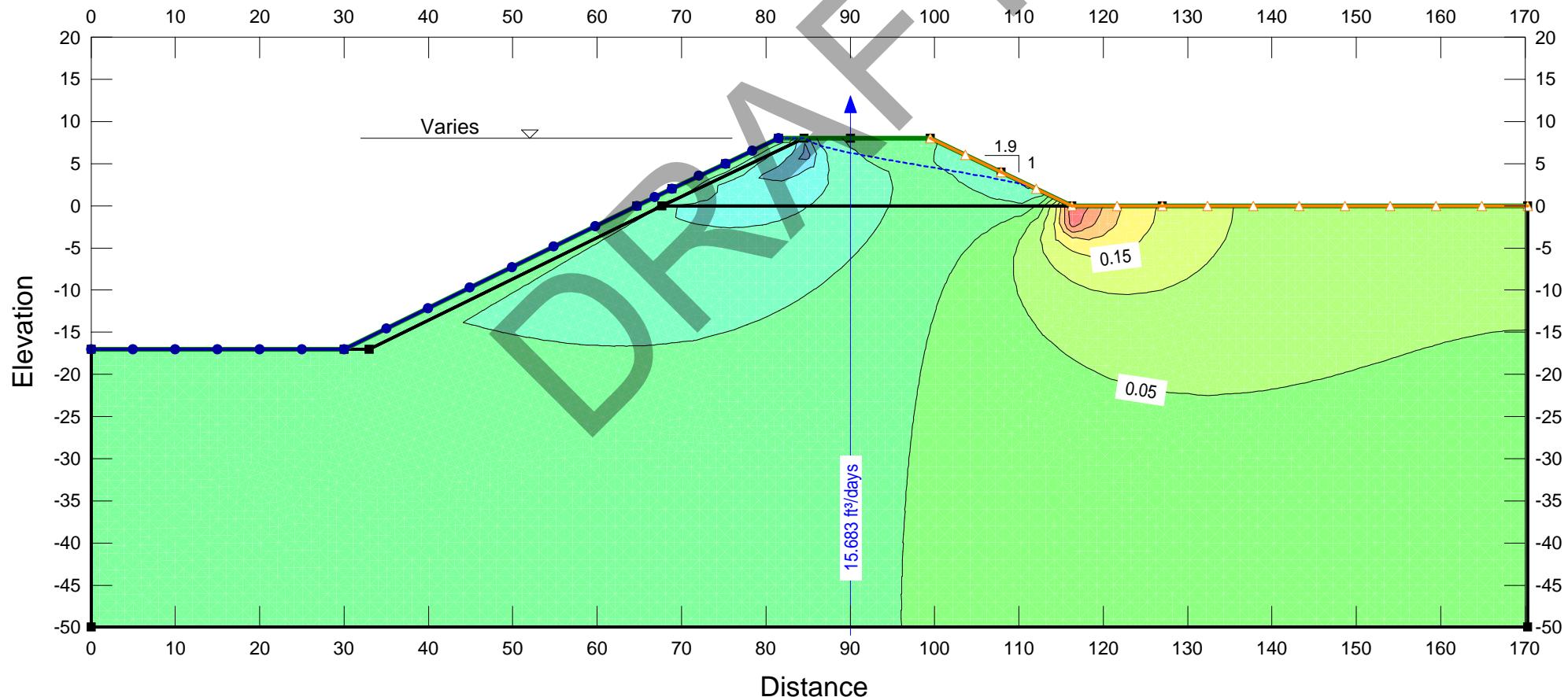


**Old Cannery Levee  
Puyallup River  
STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
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 log(K-Sat): -3 cm/s (+/- 1)  
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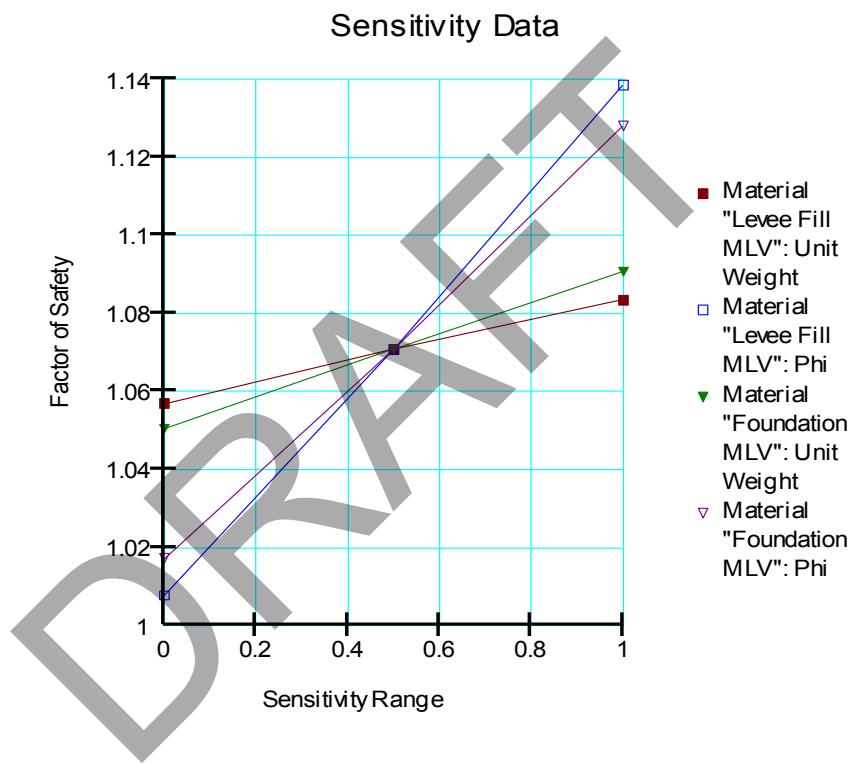
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Old Cannery
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Old Cannery Levee cross section from STA 22+87. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-3	120	33	0	0	1.07	
2	1	-3	120	33	1.5	-3	120	33	0	0	1.06	
3	2	-3	120	33	1.5	-3	120	33	0	0	1.08	0.02
4	1.5	-4	120	33	1.5	-3	120	33	0	0	1.18	
5	1.5	-2	120	33	1.5	-3	120	33	0	0	0.96	-0.22
6	1.5	-3	115	33	1.5	-3	120	33	0	0	1.06	
7	1.5	-3	125	33	1.5	-3	120	33	0	0	1.08	0.02647
8	1.5	-3	120	30	1.5	-3	120	33	0	0	0.95	
9	1.5	-3	120	36	1.5	-3	120	33	0	0	1.14	0.18851
10	1.5	-3	120	33	1	-3	120	33	0	0	1.11	
11	1.5	-3	120	33	2	-3	120	33	0	0	1.05	-0.06
12	1.5	-3	120	33	1.5	-4	120	33	0	0	0.96	
13	1.5	-3	120	33	1.5	-2	120	33	0	0	1.18	0.22
14	1.5	-3	120	33	1.5	-3	115	33	0	0	1.05	
15	1.5	-3	120	33	1.5	-3	125	33	0	0	1.09	0.0402
16	1.5	-3	120	33	1.5	-3	120	30	0	0	1.02	
17	1.5	-3	120	33	1.5	-3	120	36	0	0	1.13	0.11087
18	1.5	-3	120	33	1.5	-3	120	33	0	0		0
19	1.5	-3	120	33	1.5	-3	120	33	0	0		0
20	1.5	-3	120	33	1.5	-3	120	33	0	0		
21	1.5	-3	120	33	1.5	-3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.194
Coefficient of variation of F,	$V_F$	0.181
Log normal reliability index,	$\beta_{LN}$	0.290
Reliability		0.614
Probability of failure		0.386

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.0569289	1.0077526	1.0505217	1.0172048
0.5	1.0707093	1.0707093	1.0707093	1.0707093
1	1.0834004	1.1385148	1.0907207	1.1280707

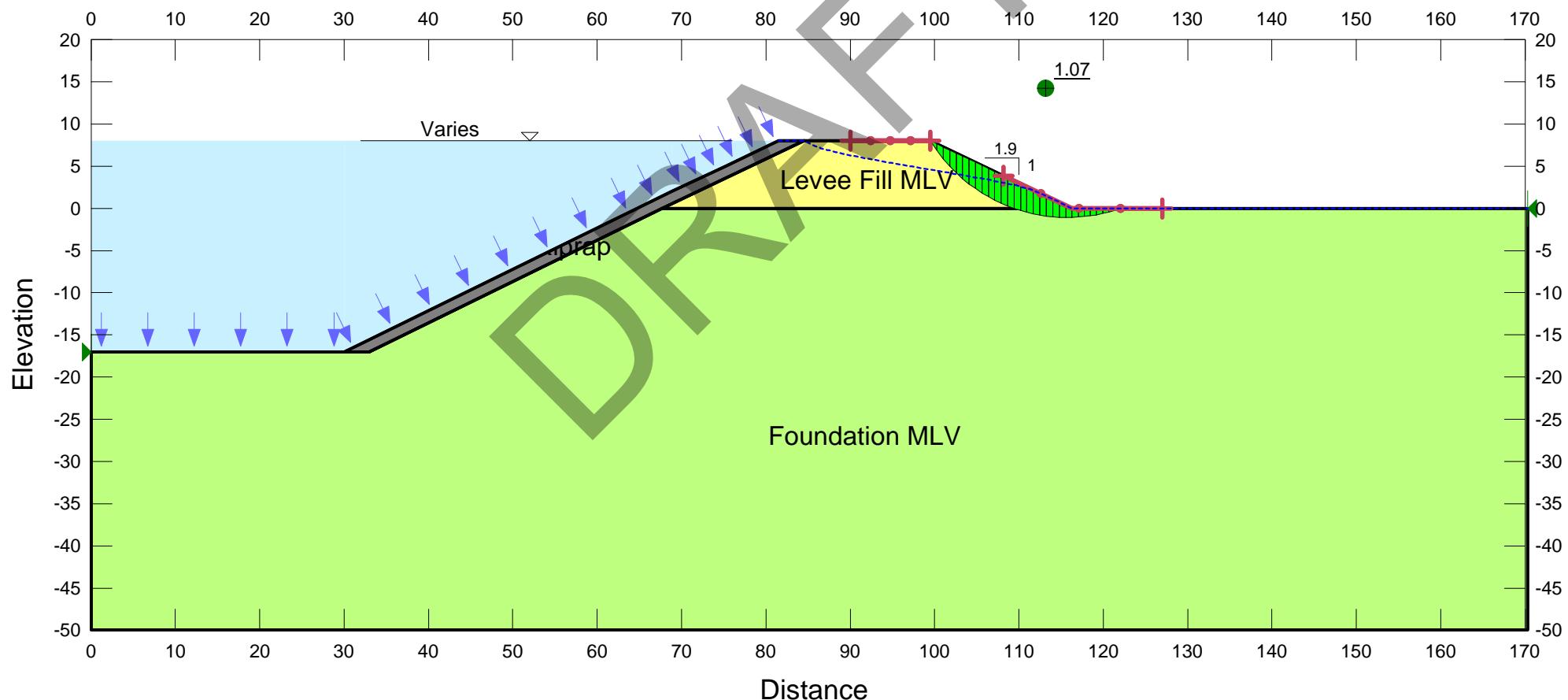


**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Old Cannery
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Old Cannery Levee cross section from STA 22+87. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-3	0	0	0	0	0	6.28	
2	52.6	1.5	1.5	-3	-3	0	0	0	0	0	5.73	
3	62.6	1.5	1.5	-3	-3	0	0	0	0	0	6.82	1.09018
4	57.6	1	1.5	-3	-3	0	0	0	0	0	5.77	
5	57.6	2	1.5	-3	-3	0	0	0	0	0	6.74	0.96856
6	57.6	1.5	1	-3	-3	0	0	0	0	0	6.15	
7	57.6	1.5	2	-3	-3	0	0	0	0	0	4.62	-1.53846
8	57.6	1.5	1.5	-4	-3	0	0	0	0	0	4.40	
9	57.6	1.5	1.5	-2	-3	0	0	0	0	0	6.15	1.75824
10	57.6	1.5	1.5	-3	-4	0	0	0	0	0	4.20	
11	57.6	1.5	1.5	-3	-2	0	0	0	0	0	5.96	1.75953
12	57.6	1.5	1.5	-3	0	0	0	0	0	0		
13	57.6	1.5	1.5	-3	0	0	0	0	0	0		
14	57.6	1.5	1.5	-3	0	0	0	0	0	0		
15	57.6	1.5	1.5	-3	0	0	0	0	0	0		
16	57.6	1.5	1.5	-3	0	0	0	0	0	0		
17	57.6	1.5	1.5	-3	0	0	0	0	0	0		
18	57.6	1.5	1.5	-3	0	0	0	0	0	0		
19	57.6	1.5	1.5	-3	0	0	0	0	0	0		
20	57.6	1.5	1.5	-3	0	0	0	0	0	0		
21	57.6	1.5	1.5	-3	0	0	0	0	0	0		

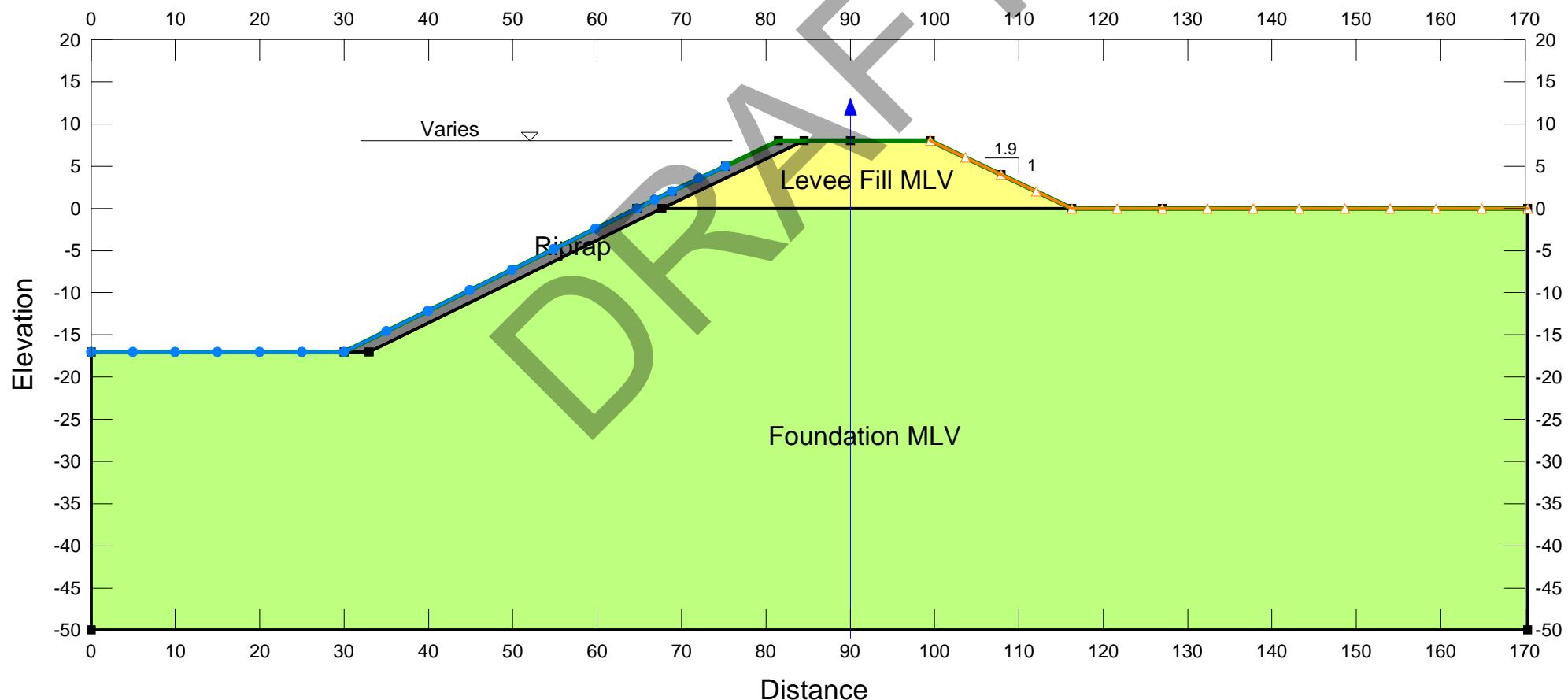
Standard deviation of F,	$\sigma_F$	1.634
Coefficient of variation of F,	$V_F$	0.260
Log normal reliability index,	$\beta_{LN}$	7.050
Reliability		1.000
Probability of failure		9.0E-13

**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
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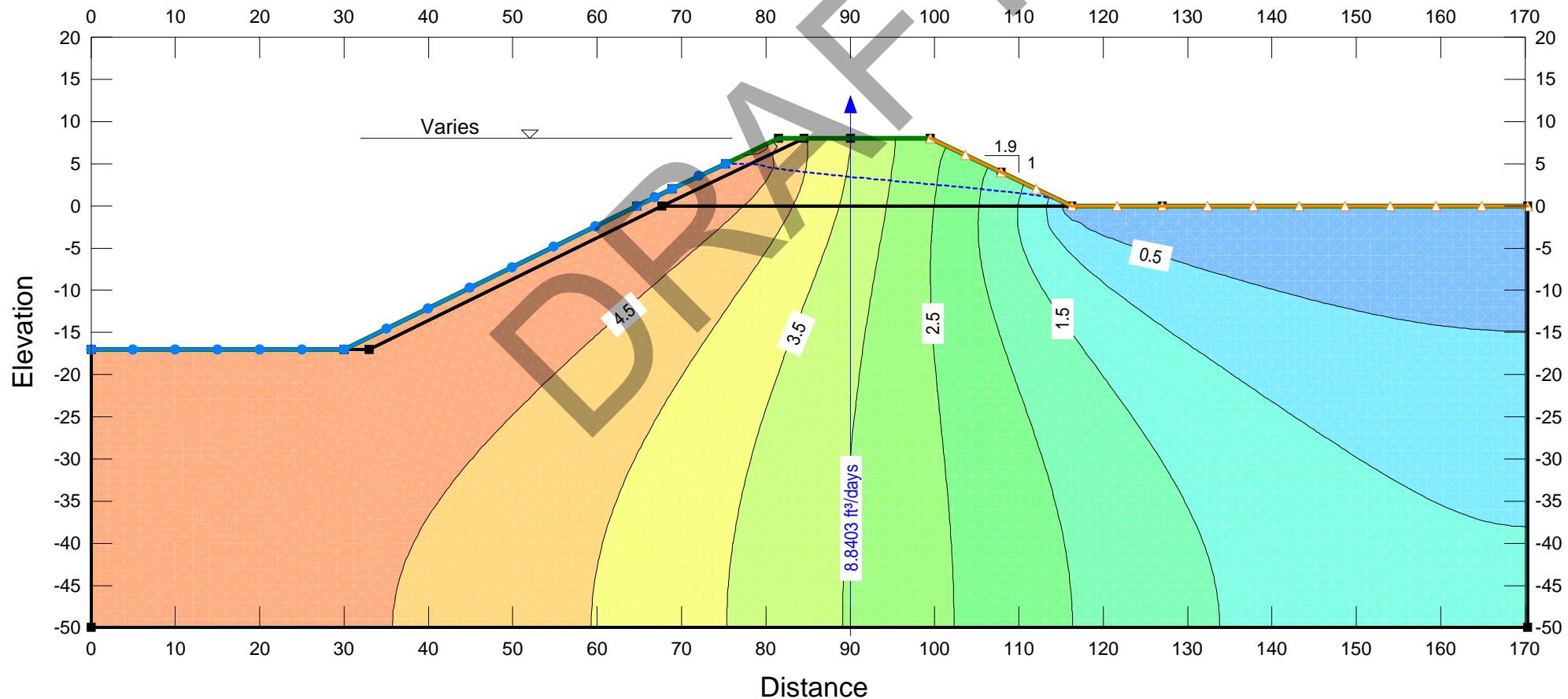


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**STA 22+87**

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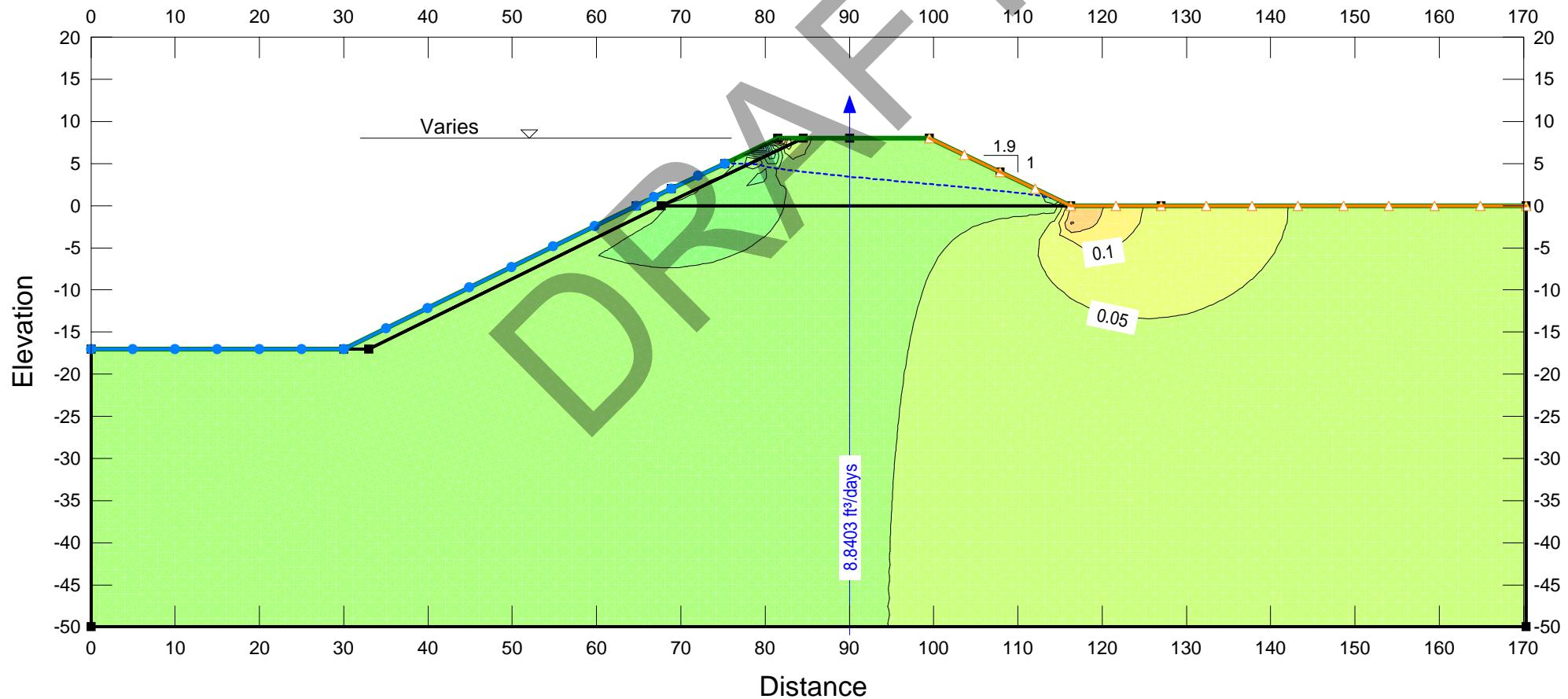


**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

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 log(K-Sat): -3 cm/s (+/- 1)  
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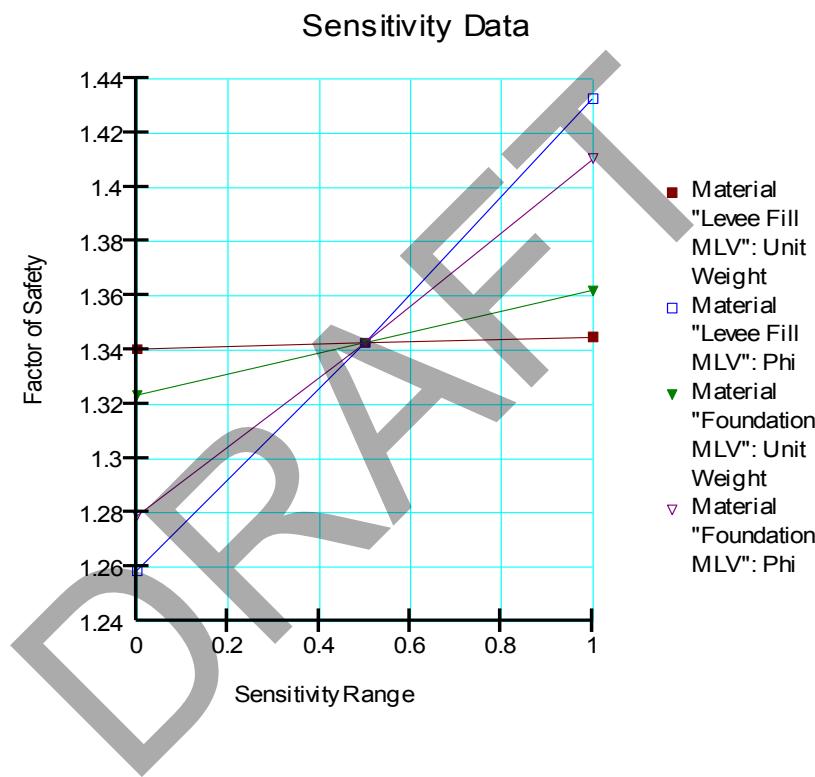
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Old Cannery
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Old Cannery Levee cross section from STA 22+87. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-3	120	33	0	0	1.34	
2	1	-3	120	33	1.5	-3	120	33	0	0	1.34	
3	2	-3	120	33	1.5	-3	120	33	0	0	1.35	0.01
4	1.5	-4	120	33	1.5	-3	120	33	0	0	1.39	
5	1.5	-2	120	33	1.5	-3	120	33	0	0	1.26	-0.13
6	1.5	-3	115	33	1.5	-3	120	33	0	0	1.34	
7	1.5	-3	125	33	1.5	-3	120	33	0	0	1.34	0.00447
8	1.5	-3	120	30	1.5	-3	120	33	0	0	1.26	
9	1.5	-3	120	36	1.5	-3	120	33	0	0	1.43	0.17395
10	1.5	-3	120	33	1	-3	120	33	0	0	1.37	
11	1.5	-3	120	33	2	-3	120	33	0	0	1.33	-0.04
12	1.5	-3	120	33	1.5	-4	120	33	0	0	1.26	
13	1.5	-3	120	33	1.5	-2	120	33	0	0	1.39	0.13
14	1.5	-3	120	33	1.5	-3	115	33	0	0	1.32	
15	1.5	-3	120	33	1.5	-3	125	33	0	0	1.36	0.03842
16	1.5	-3	120	33	1.5	-3	120	30	0	0	1.28	
17	1.5	-3	120	33	1.5	-3	120	36	0	0	1.41	0.13142
18	1.5	-3	120	33	1.5	-3	120	33	0	0		
19	1.5	-3	120	33	1.5	-3	120	33	0	0		0
20	1.5	-3	120	33	1.5	-3	120	33	0	0		
21	1.5	-3	120	33	1.5	-3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.145
Coefficient of variation of F,	$V_F$	0.108
Log normal reliability index,	$\beta_{LN}$	2.676
Reliability		0.996
Probability of failure		0.004

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.3404018	1.2588026	1.323463	1.2791881
0.5	1.3427324	1.3427324	1.3427324	1.3427324
1	1.3448744	1.4327532	1.361879	1.4106122

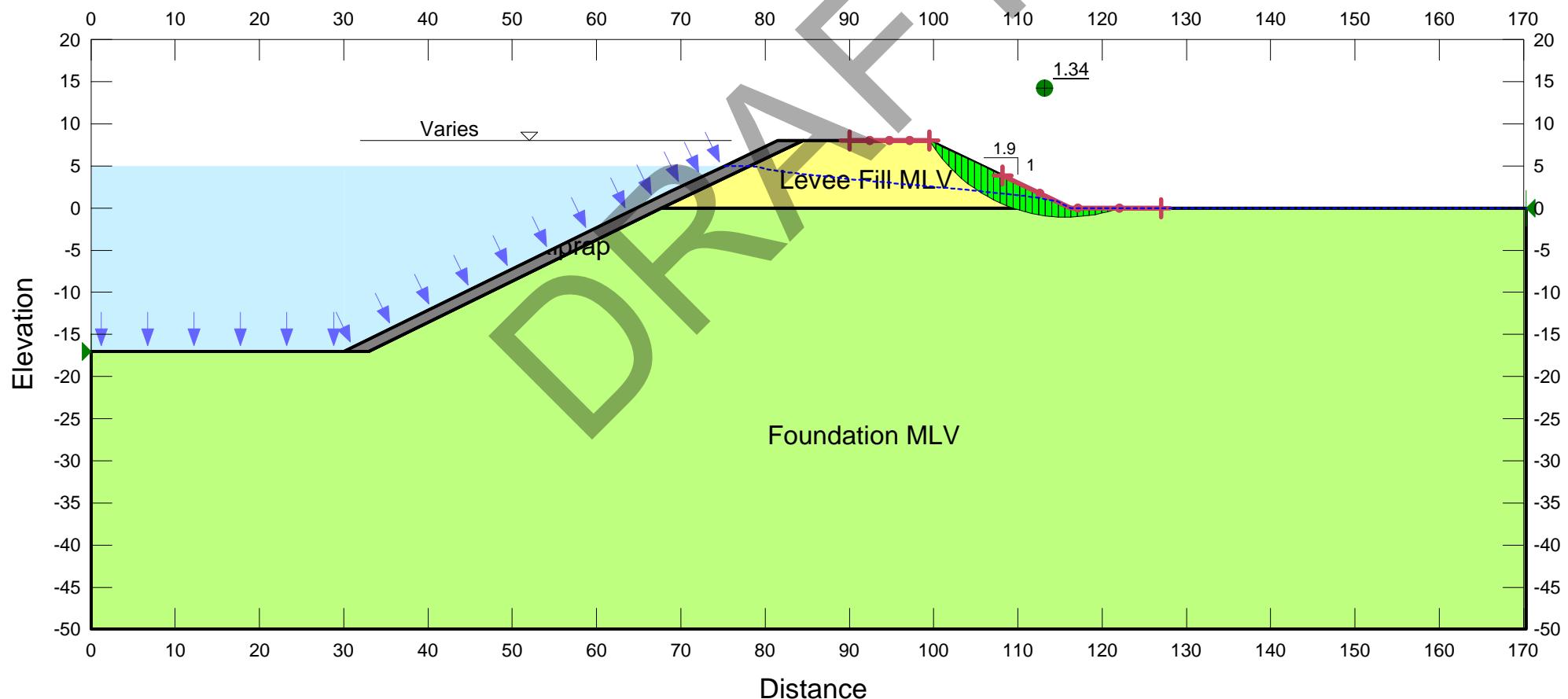


**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Old Cannery
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Old Cannery Levee cross section from STA 22+87. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-3	0	0	0	0	0	12.33	
2	52.6	1.5	1.5	-3	-3	0	0	0	0	0	11.26	
3	62.6	1.5	1.5	-3	-3	0	0	0	0	0	13.40	2.13989
4	57.6	1	1.5	-3	-3	0	0	0	0	0	13.19	
5	57.6	2	1.5	-3	-3	0	0	0	0	0	13.19	0
6	57.6	1.5	1	-3	-3	0	0	0	0	0	15.38	
7	57.6	1.5	2	-3	-3	0	0	0	0	0	11.54	-3.84615
8	57.6	1.5	1.5	-4	-3	0	0	0	0	0	13.19	
9	57.6	1.5	1.5	-2	-3	0	0	0	0	0	11.54	-1.64835
10	57.6	1.5	1.5	-3	-4	0	0	0	0	0	11.54	
11	57.6	1.5	1.5	-3	-2	0	0	0	0	0	13.19	1.64835
12	57.6	1.5	1.5	-3	0	0	0	0	0	0		
13	57.6	1.5	1.5	-3	0	0	0	0	0	0		
14	57.6	1.5	1.5	-3	0	0	0	0	0	0		
15	57.6	1.5	1.5	-3	0	0	0	0	0	0		
16	57.6	1.5	1.5	-3	0	0	0	0	0	0		
17	57.6	1.5	1.5	-3	0	0	0	0	0	0		
18	57.6	1.5	1.5	-3	0	0	0	0	0	0		
19	57.6	1.5	1.5	-3	0	0	0	0	0	0		
20	57.6	1.5	1.5	-3	0	0	0	0	0	0		
21	57.6	1.5	1.5	-3	0	0	0	0	0	0		

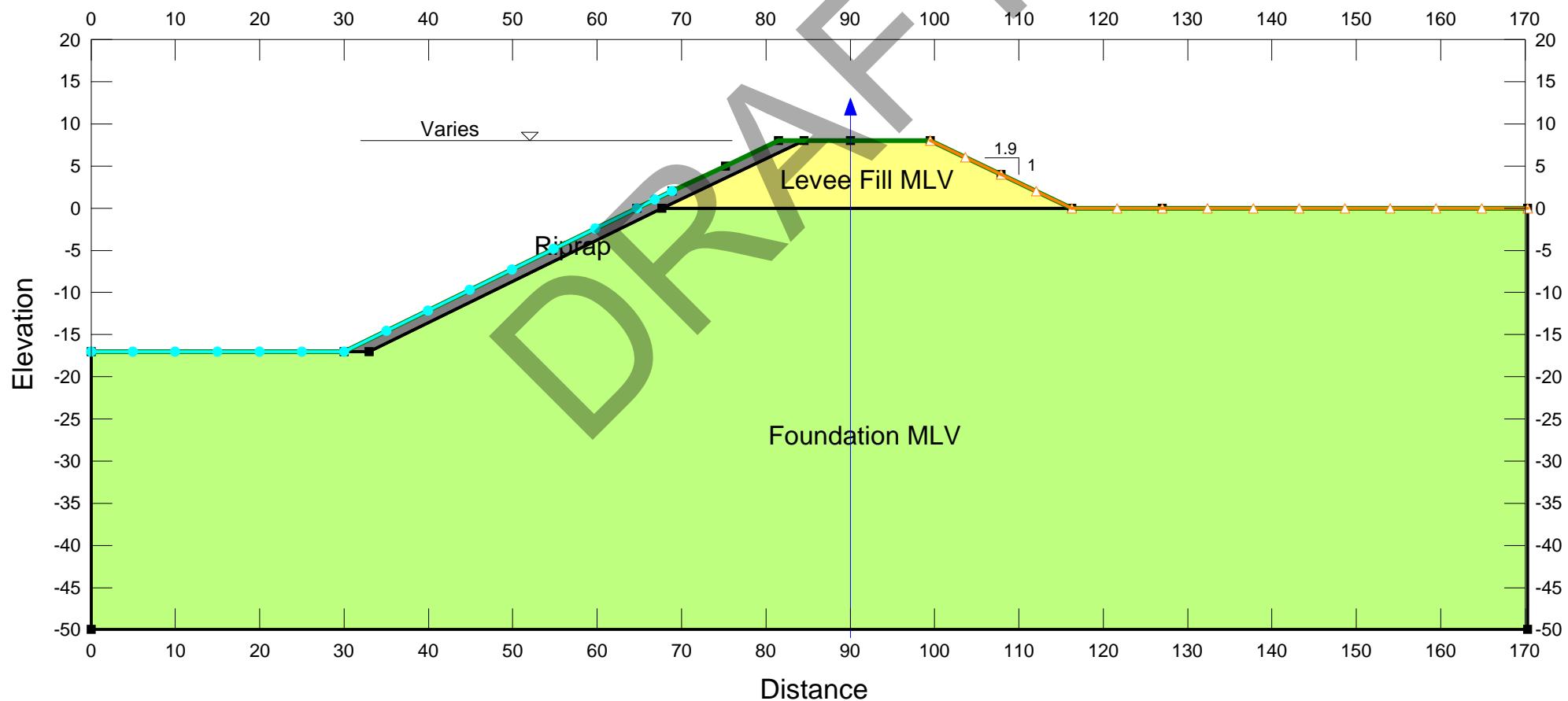
Standard deviation of F,	$\sigma_F$	2.490
Coefficient of variation of F,	$V_F$	0.202
Log normal reliability index,	$\beta_{LN}$	12.457
Reliability		1.000
Probability of failure		0.0E+00

**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

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 Phi: 33 degs (+/- 3)

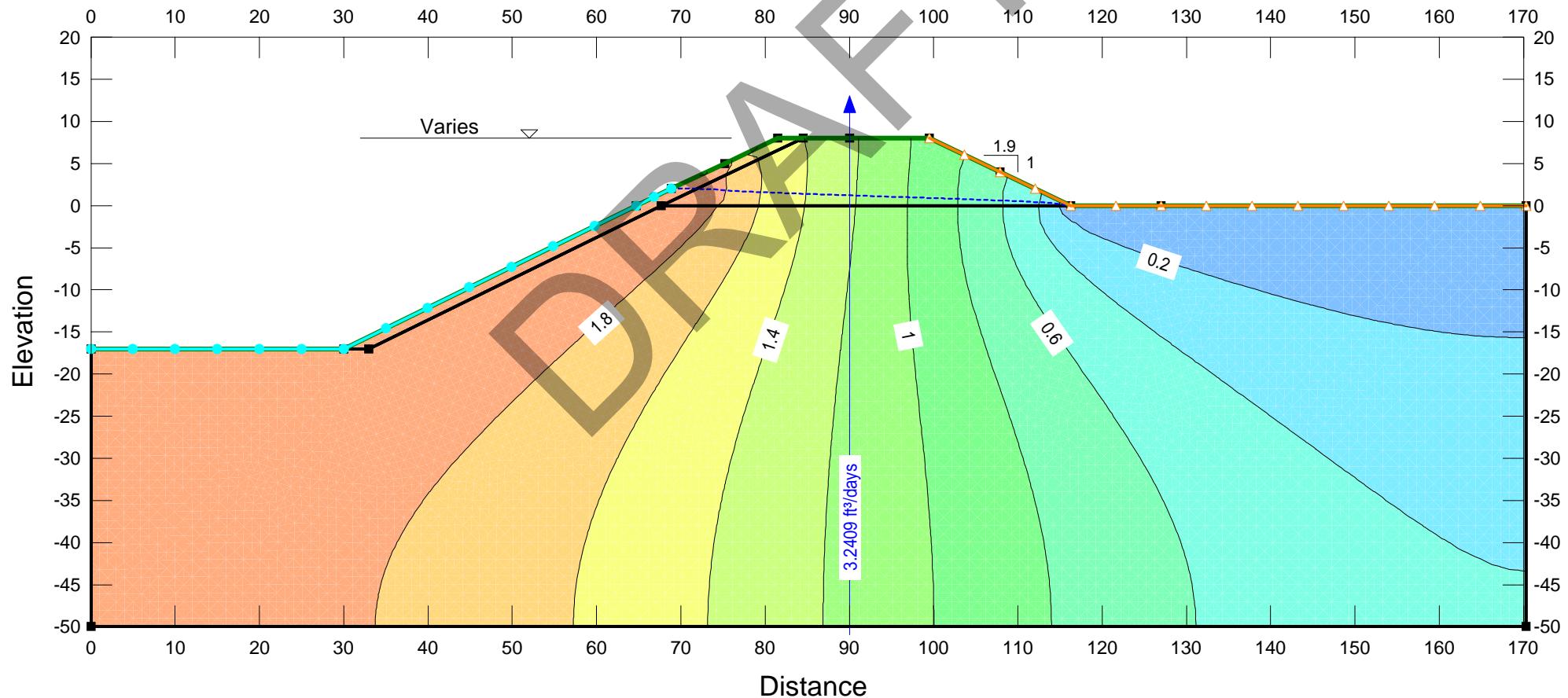


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STA 22+87**

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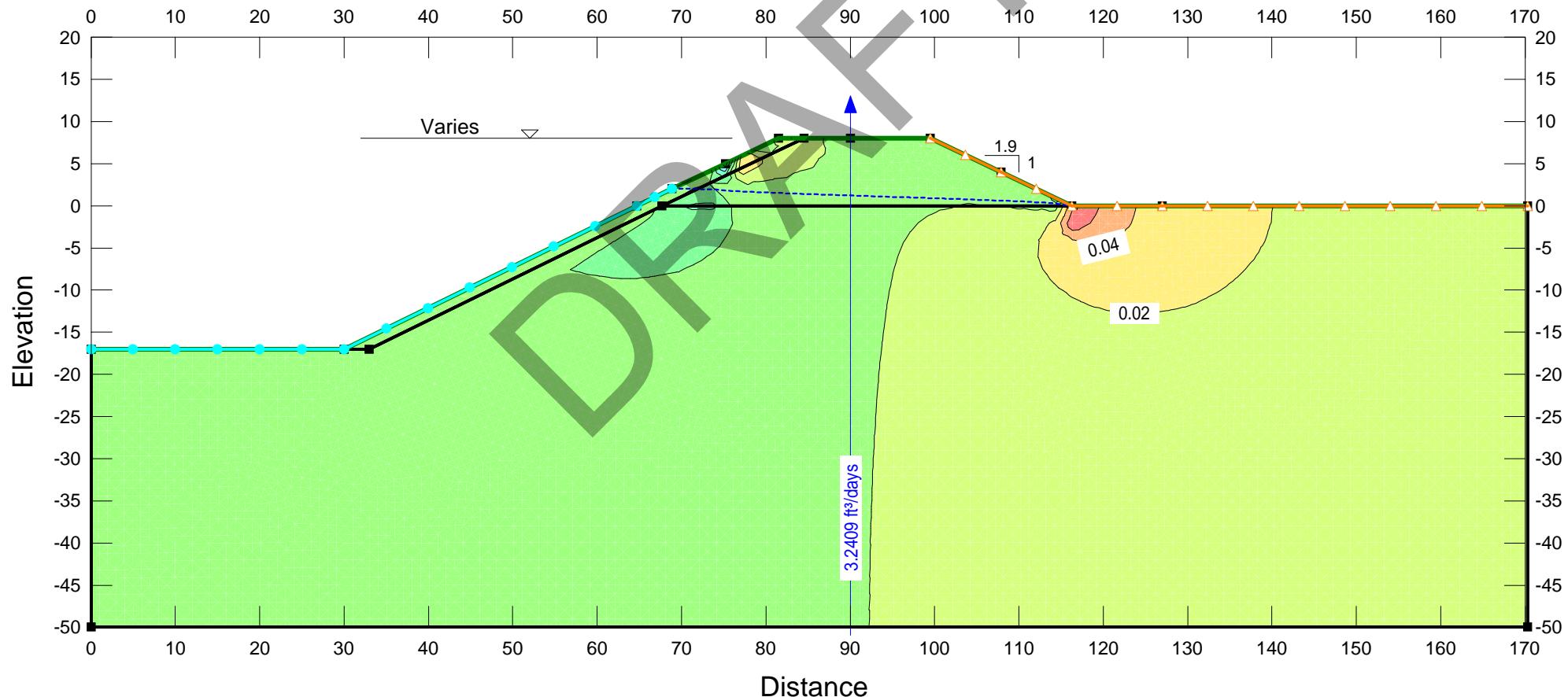


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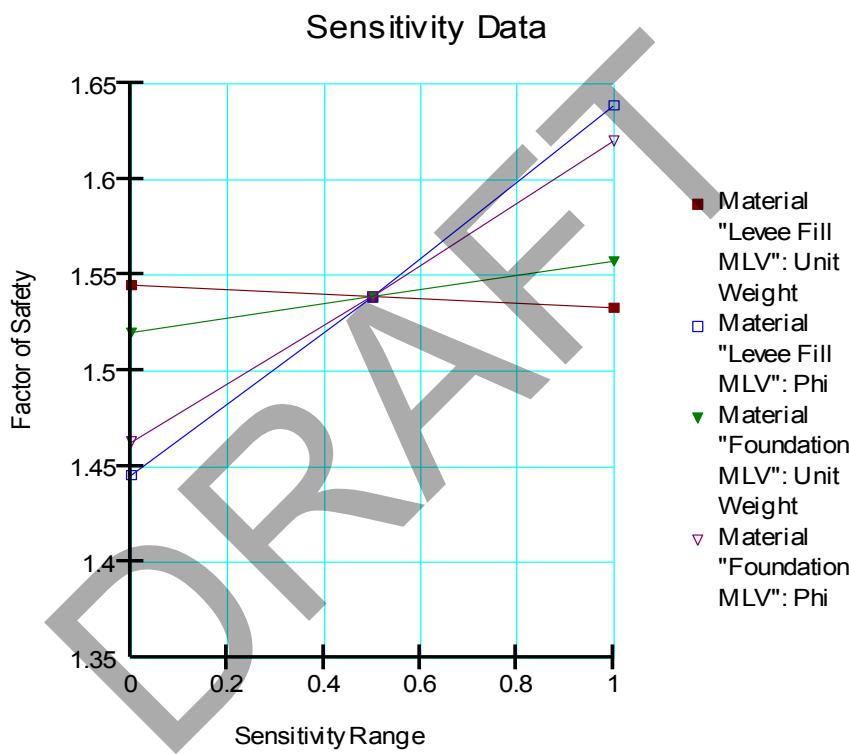
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Project	Puyallup General Investigation
Feature	Old Cannery
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Potential failure mode	Slope Stability
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Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Old Cannery Levee cross section from STA 22+87. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-3	120	33	0	0	1.54	
2	1	-3	120	33	1.5	-3	120	33	0	0	1.54	
3	2	-3	120	33	1.5	-3	120	33	0	0	1.54	0
4	1.5	-4	120	33	1.5	-3	120	33	0	0	1.54	
5	1.5	-2	120	33	1.5	-3	120	33	0	0	1.52	-0.02
6	1.5	-3	115	33	1.5	-3	120	33	0	0	1.54	
7	1.5	-3	125	33	1.5	-3	120	33	0	0	1.53	-0.01157
8	1.5	-3	120	30	1.5	-3	120	33	0	0	1.45	
9	1.5	-3	120	36	1.5	-3	120	33	0	0	1.64	0.19295
10	1.5	-3	120	33	1	-3	120	33	0	0	1.55	
11	1.5	-3	120	33	2	-3	120	33	0	0	1.53	-0.02
12	1.5	-3	120	33	1.5	-4	120	33	0	0	1.52	
13	1.5	-3	120	33	1.5	-2	120	33	0	0	1.54	0.02
14	1.5	-3	120	33	1.5	-3	115	33	0	0	1.52	
15	1.5	-3	120	33	1.5	-3	125	33	0	0	1.56	0.03717
16	1.5	-3	120	33	1.5	-3	120	30	0	0	1.46	
17	1.5	-3	120	33	1.5	-3	120	36	0	0	1.62	0.15721
18	1.5	-3	120	33	1.5	-3	120	33	0	0		
19	1.5	-3	120	33	1.5	-3	120	33	0	0		0
20	1.5	-3	120	33	1.5	-3	120	33	0	0		
21	1.5	-3	120	33	1.5	-3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.127
Coefficient of variation of F,	$V_F$	0.083
Log normal reliability index,	$\beta_{LN}$	5.184
Reliability		1.000
Probability of failure		1.1E-07

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.5448257	1.4458659	1.5201767	1.4631224
0.5	1.5388062	1.5388062	1.5388062	1.5388062
1	1.533255	1.6388121	1.5573471	1.6203363

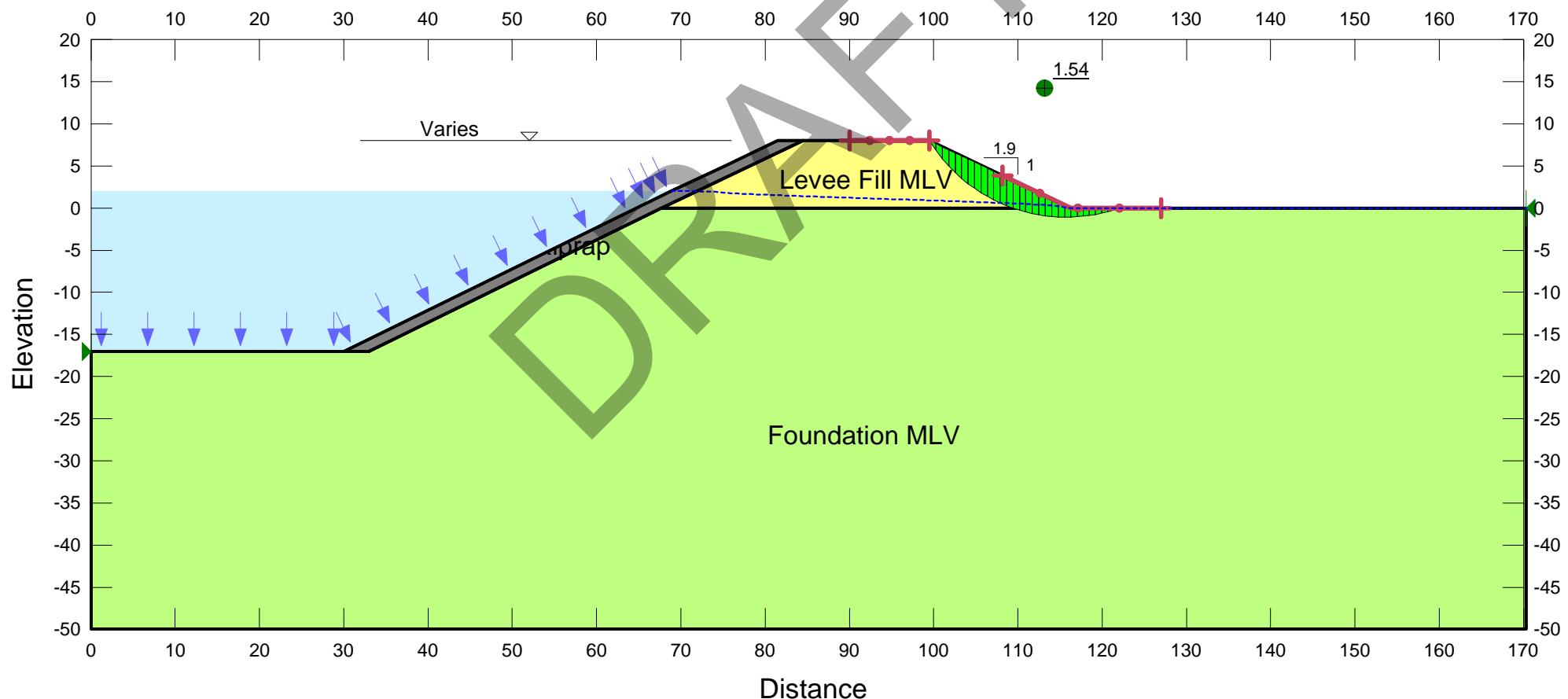


**Old Cannery Levee**  
**Puyallup River**  
**STA 22+87**

**Levee Fill (SP-SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SM)**  
 log(K-Sat): -3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	Old Soldiers Home
<b>Station:</b>	10+00

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is acceptable per USACE guidance. No maintenance issues were noted.

#### Levee Geometry

Crown Width (W)	15 Feet
Landward Levee Height (H)	4 Feet
Riverward Slope (R)	2 H:1V
Landward Slope (L)	2 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	4 Feet
Breach Width at Top of Levee	89.6 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.78 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is assumed to be a medium dense poorly graded GRAVEL with sand (GP) alluvium.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
	Loose / Soft	Low
	Medium	Medium
X	Dense / Stiff	X High

**Remarks:** Levee embankment material is assumed to be a dense GRAVEL with silt and sand (GP-GM).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
204.76	1.00
204.76	0.24
203.76	0.18
202.76	0.12
200.76	0.04

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

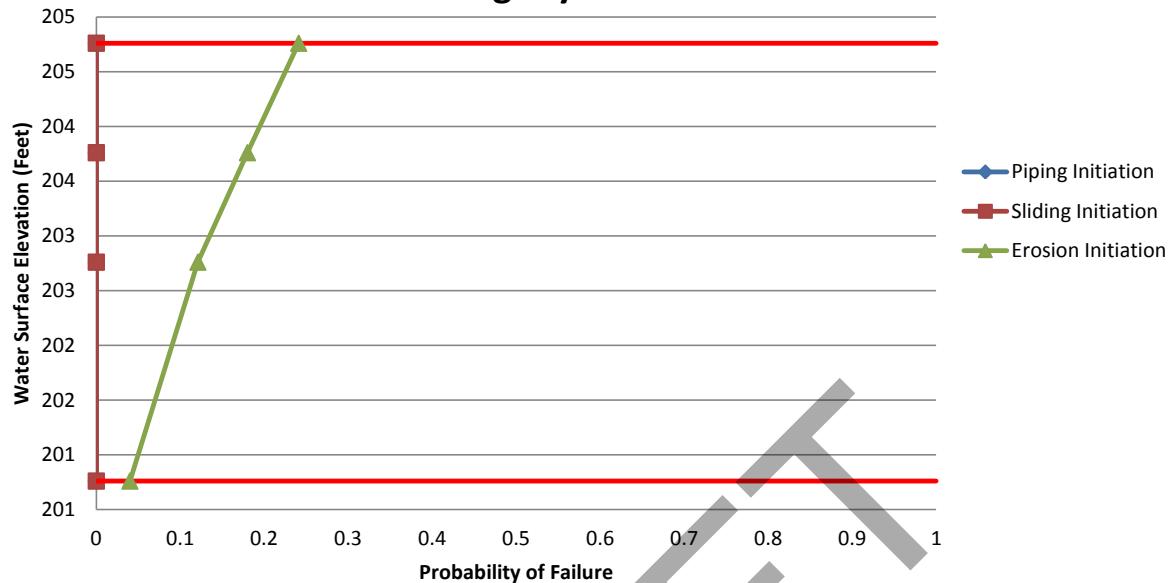
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

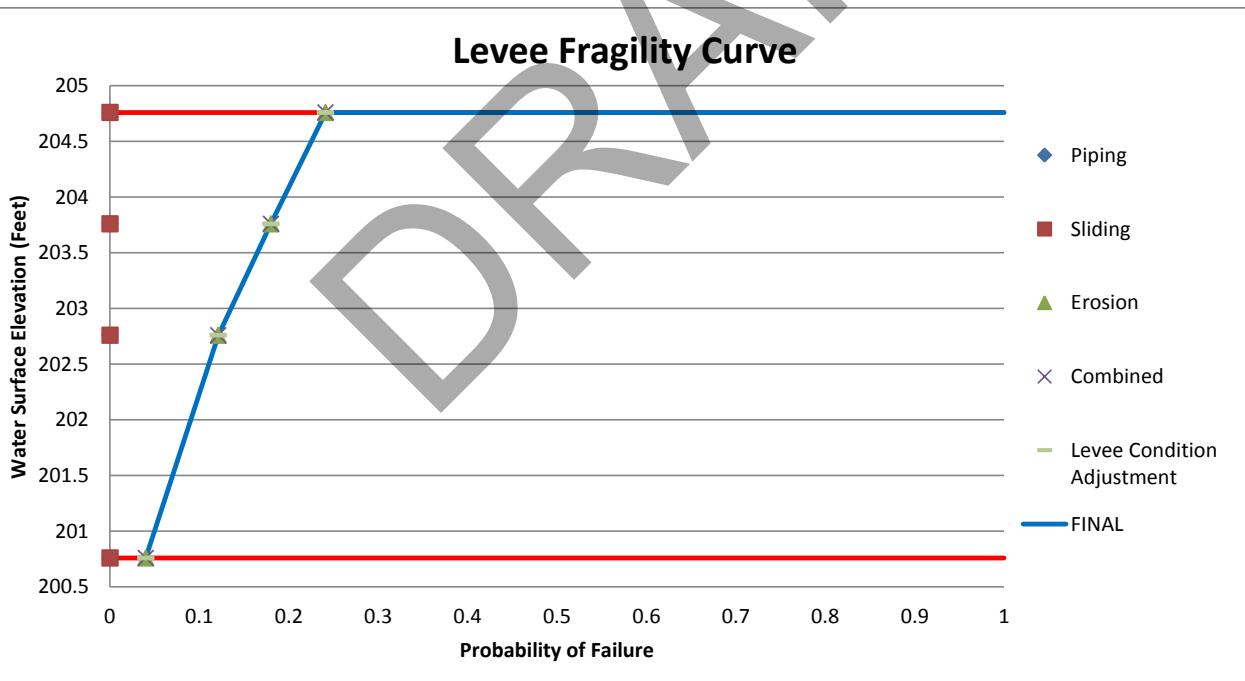
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



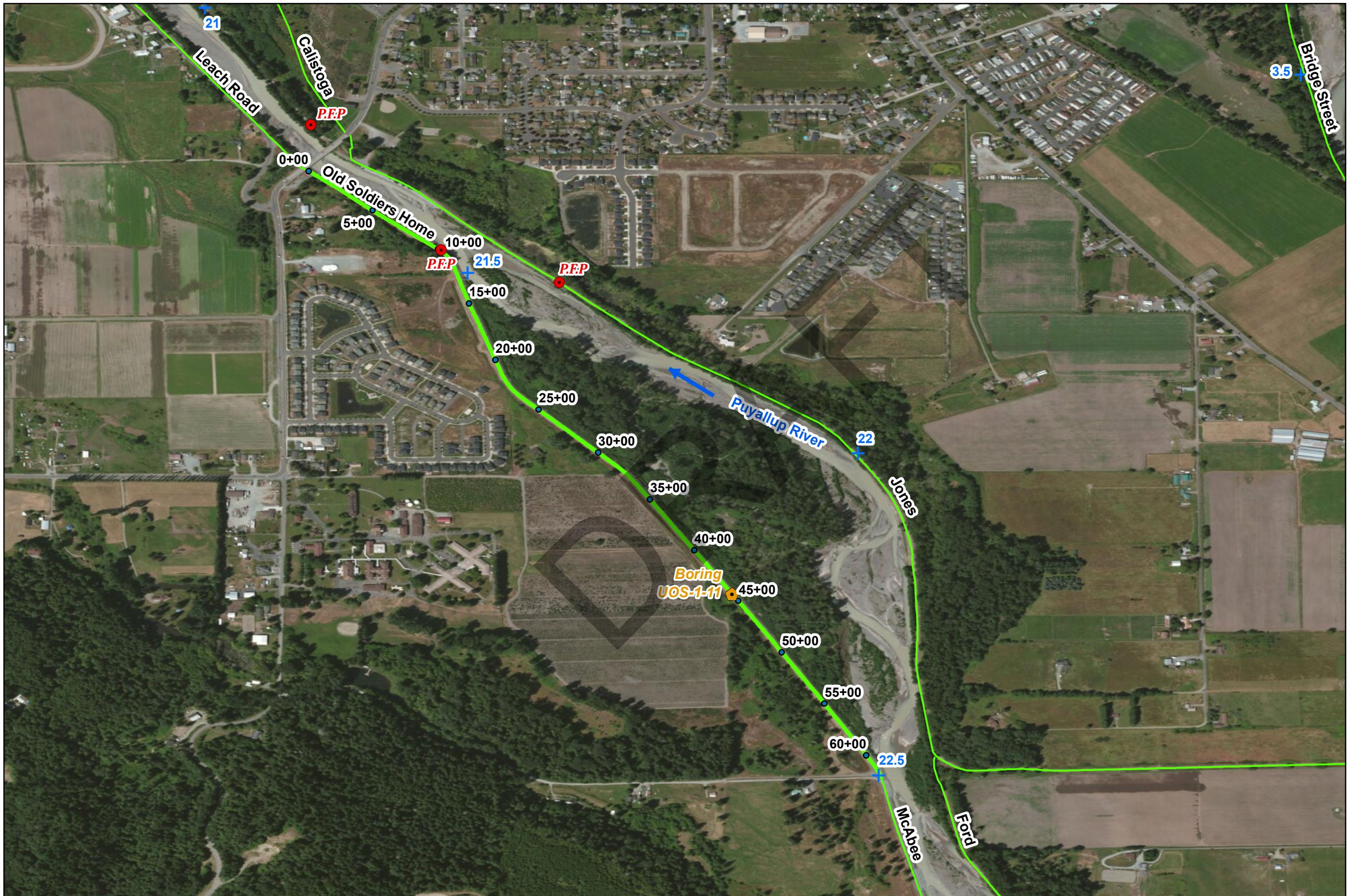
*Remarks: Fragility curve above displays the fragility curve at initiation only. No adjustments.*

### Levee Fragility Curve



*Remarks: The final levee fragility curve for the Old Soldiers Home Levee was determined by engineering judgment and erosion analysis. The levee has two distinct cross sections: a setback and a segment that lines the channel. A toe drain was installed at the setback levee to mitigate seepage issues. The cross section lining the channel is assumed similar to Jones & Ford levees with free draining foundations and essentially no seepage or sliding issues. Therefore, the erosion failure mode governs. Levee condition was found not to significantly increase the probability of failure.*

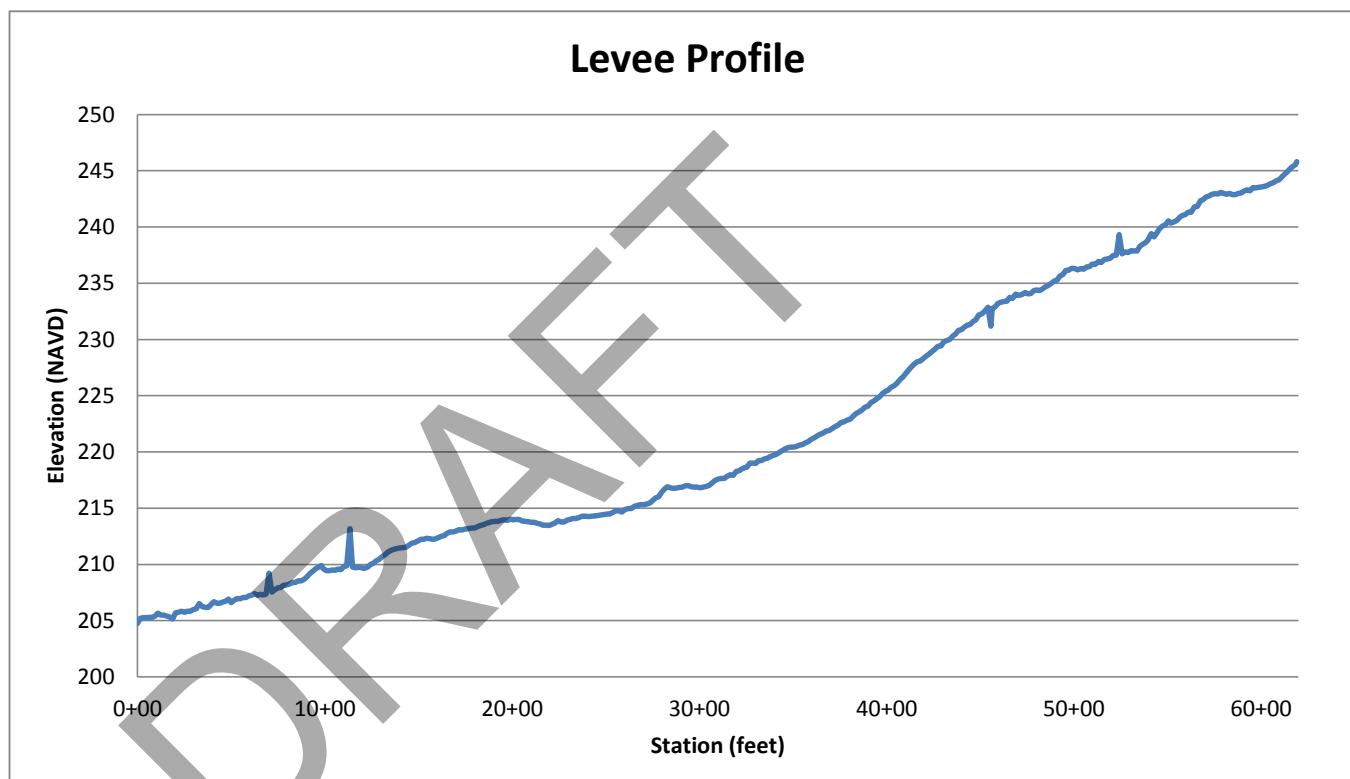
# Old Soldiers Home Levee - Puyallup River



**Old Soldiers Home Levee**  
**Puyallup River**

<b>Min</b>	204.76
<b>Max</b>	245.80

<b>Station Begin</b>	0+00
<b>Station End</b>	61+92



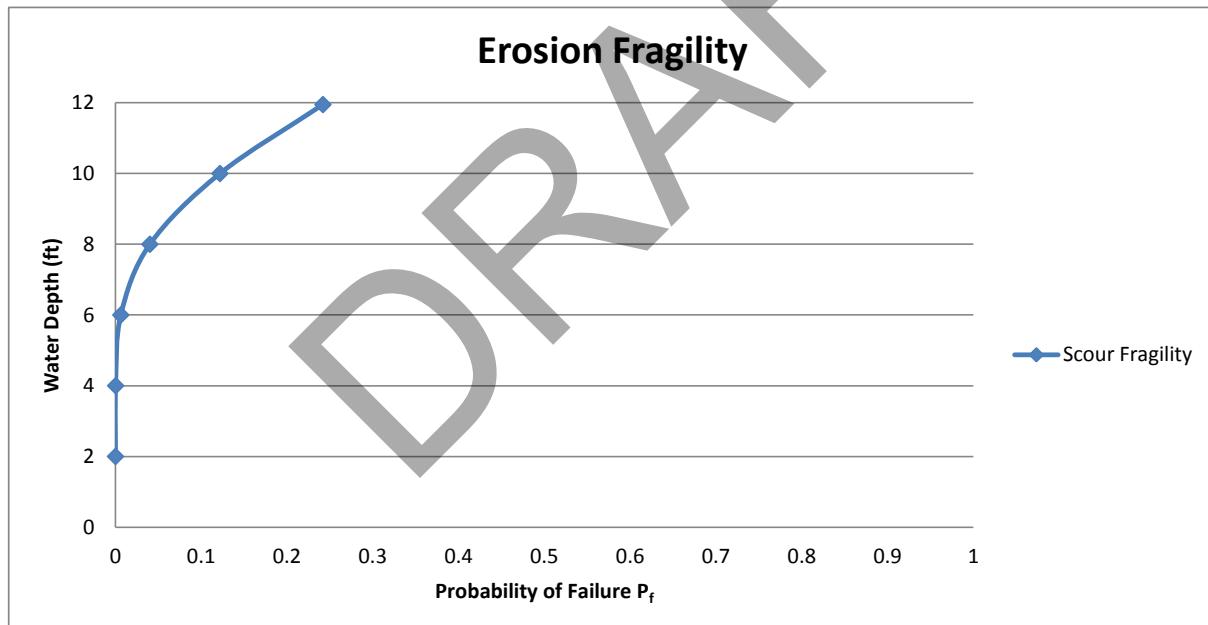
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Old Soldiers Home Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0071	CV(s) =	0.1	0.00071
Manning's "n"	n =	0.055	CV(n) =	0.15	0.00825
Scouring Velocity		V <sub>crit</sub> = 14.23	CV(v <sub>crit</sub> )		2.85

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	3.614	0.1581139		-1.370327665	0.254950976	-5.37487	3.832E-08
4	5.737	0.1581139		-0.908229545	0.254950976	-3.56237	0.00018376
6	7.517	0.1581139		-0.637919473	0.254950976	-2.50213	0.0061725
8	9.106	0.1581139		-0.446131424	0.254950976	-1.74987	0.04007025
10	10.567	0.1581139		-0.297369057	0.254950976	-1.16638	0.12173095
11.95	11.900	0.1581139		-0.178604933	0.254950976	-0.70055	0.24179314



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Orting Treatment Plant Cross Section Model & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Carbon River
<b>Levee Segment Name:</b>	Orting Treatment Plant
<b>Station:</b>	4+22

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Vegetation maintenance issues and minor toe scour damage were noted.

#### Levee Geometry

Crown Width (W)	21 Feet
Landward Levee Height (H)	6 Feet
Riverward Slope (R)	2.8 H:1V
Landward Slope (L)	5.5 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	6 Feet
Breach Width at Top of Levee	134 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.17 Hours*
*SERRI Report 70015-001	

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is a dense poorly graded GRAVEL with sand (GP).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
	Loose / Soft	Low
X	Medium	X Medium
	Dense / Stiff	High

**Remarks:** Levee embankment material is a medium dense poorly graded SAND with silt and gravel (SP-SM).

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

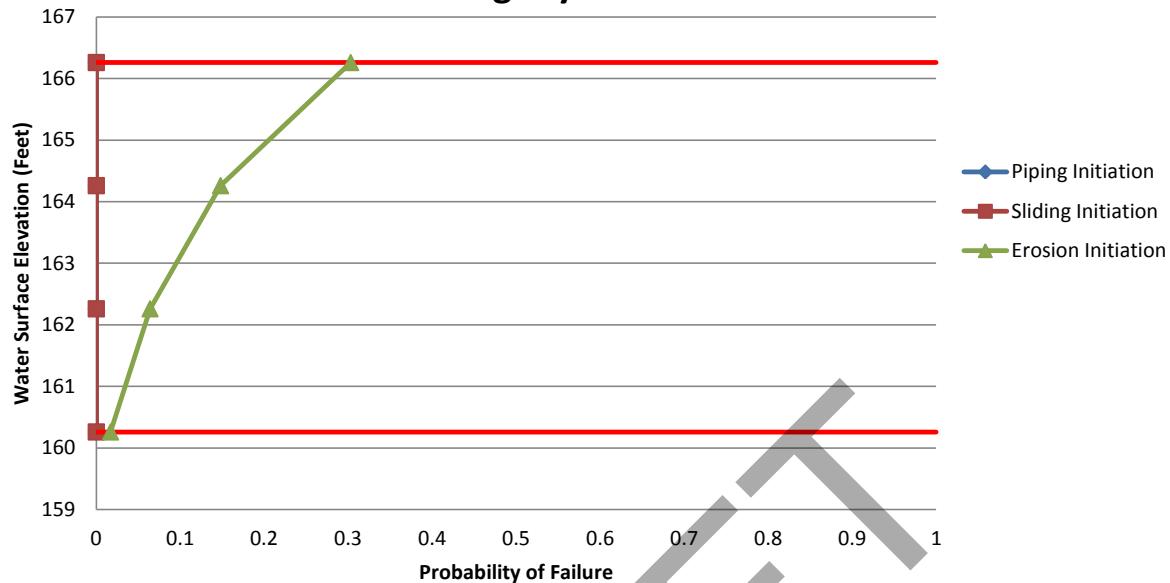
#### Final Fragility Curve

Elev.	Prob.
166.26	1.00
166.26	0.30
164.26	0.15
162.26	0.06
160.26	0.02

# PUYALLUP BASIN GENERAL INVESTIGATION

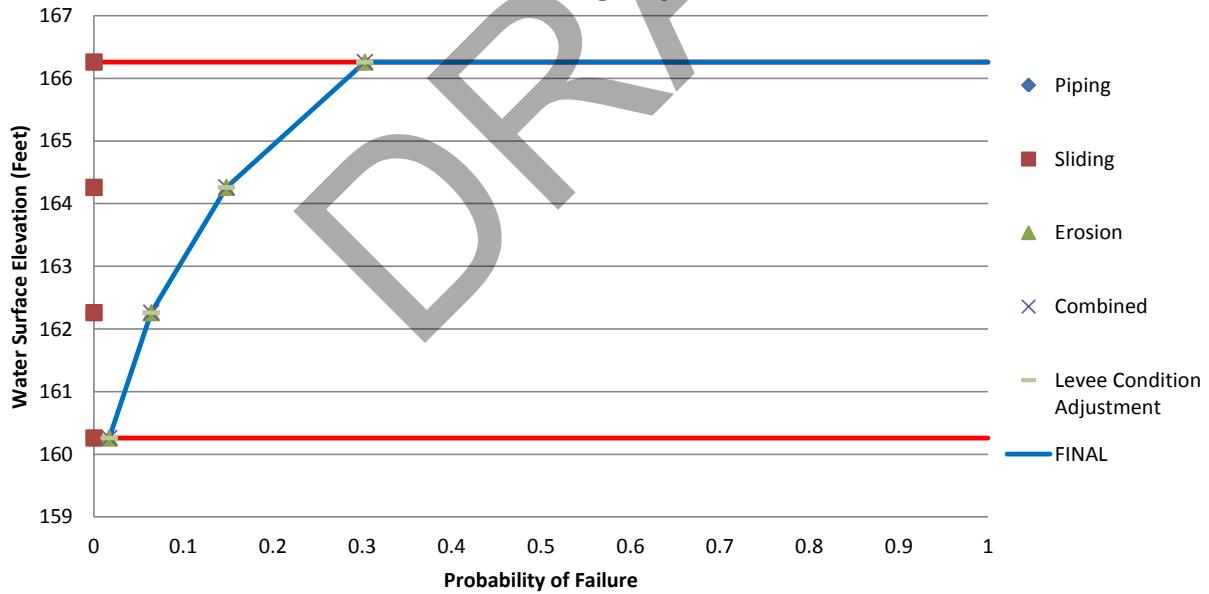
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Orting Treatment Plant Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# Orting Treatment Plant Levee - Carbon River



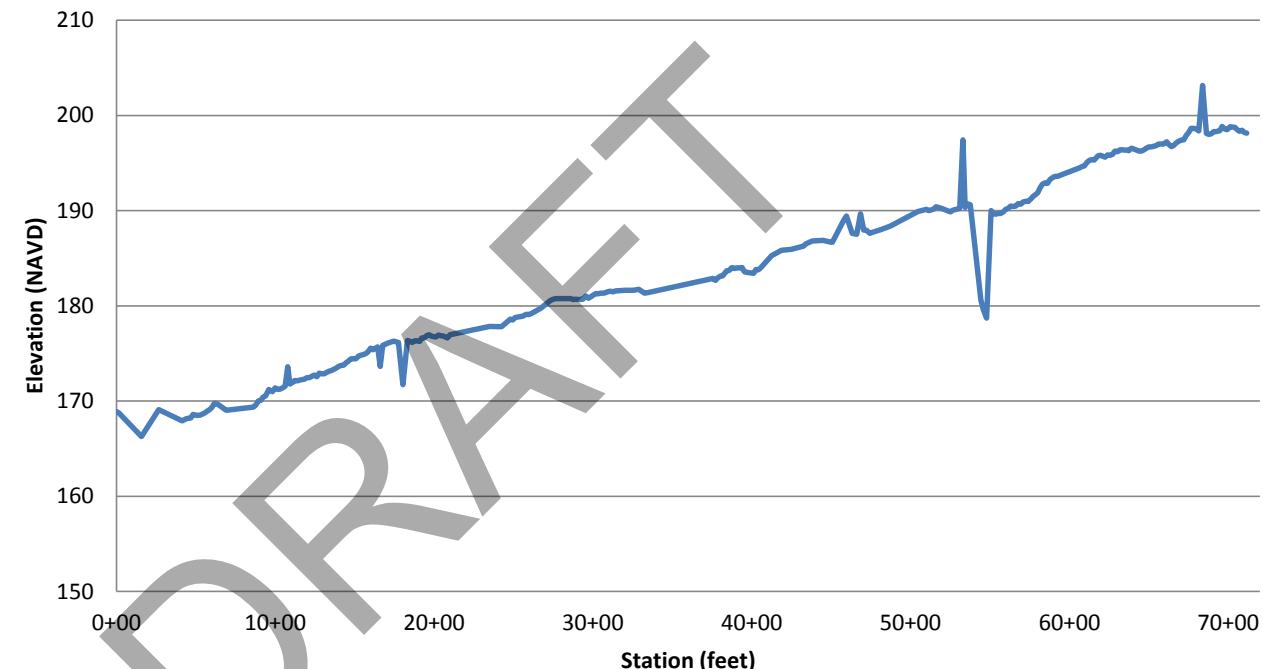
## *Orting Treatment Plant Levee*

*Carbon River*

<b>Min</b>	166.26
<b>Max</b>	203.16

<b>Station Begin</b>	0+00
<b>Station End</b>	71+17

### **Levee Profile**



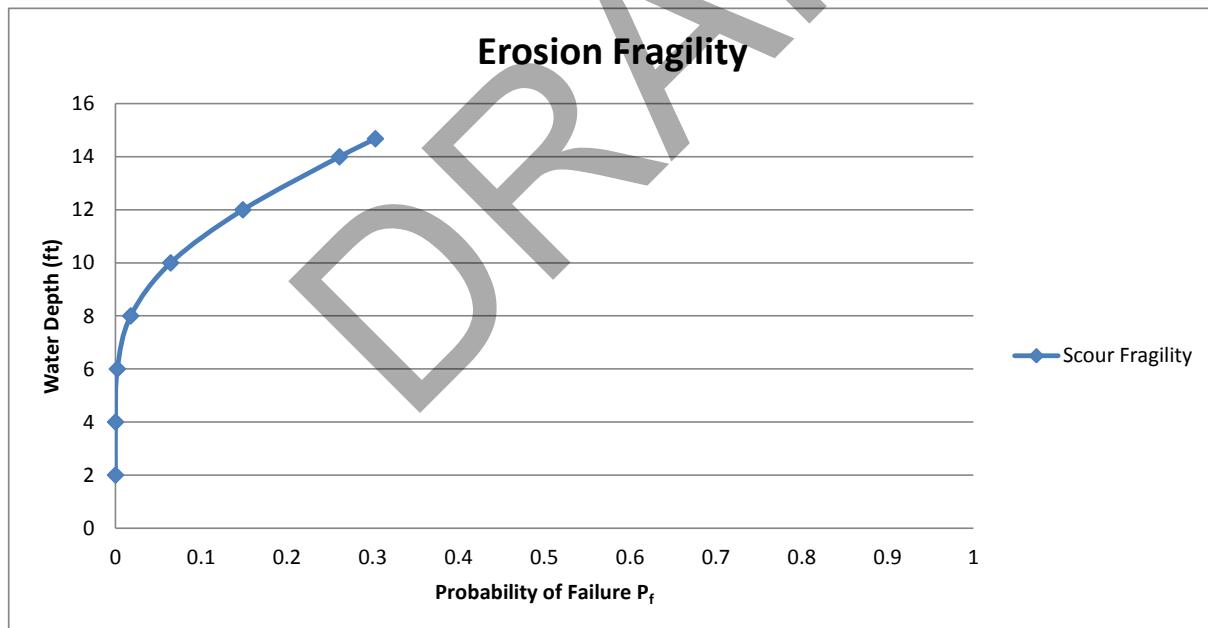
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Orting Treatment Plant Levee

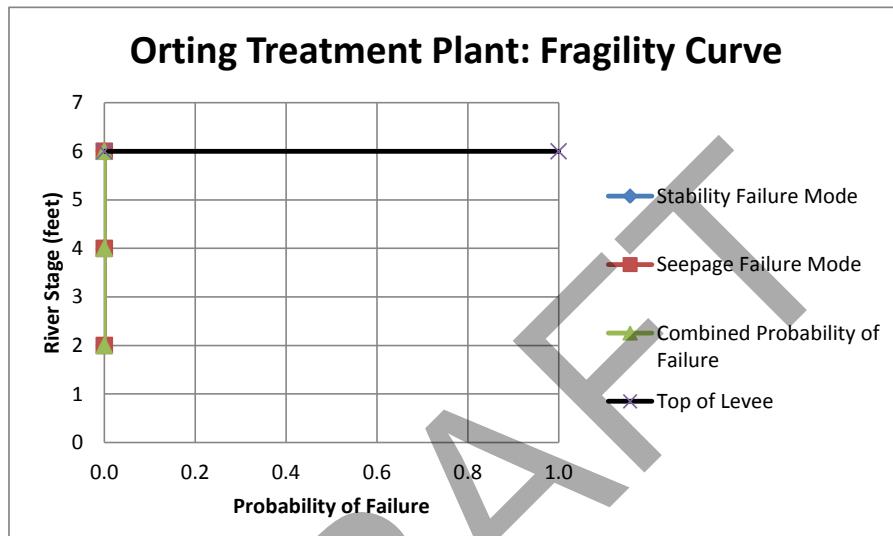
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0049	CV(s) =	0.1	0.00049
Manning's "n"	n =	0.05	CV(n) =	0.15	0.0075
Scouring Velocity	$V_{crit} =$	14.23	$CV(V_{crit})$	0.2	2.85

Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	3.302	0.1581139		-1.460447275	0.254950976	-5.72835	5.0707E-09
4	5.242	0.1581139		-0.998349154	0.254950976	-3.91585	4.5044E-05
6	6.869	0.1581139		-0.728039082	0.254950976	-2.8556	0.00214775
8	8.322	0.1581139		-0.536251034	0.254950976	-2.10335	0.01771761
10	9.656	0.1581139		-0.387488666	0.254950976	-1.51986	0.06427364
12	10.904	0.1581139		-0.265940962	0.254950976	-1.04311	0.14844954
14	12.085	0.1581139		-0.163173842	0.254950976	-0.64002	0.26107965
14.68	12.473	0.1581139		-0.131554713	0.254950976	-0.516	0.30292719



Orting Treatment Plant					
Fragility Curve					
Cross Section from STA 4+00					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 6' +					
6	2.8E-13	6	0.0E+00	6	0.000
4	0.0E+00	4	0.0E+00	4	0.000
2	0.0E+00	2	0.0E+00	2	0.000



OVERTOPPING - 6' +	Top of Levee
6	0
6	1

Soil Unit	Stability	TOL		TOL -2'		TOL -4'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	2.71	0.20	2.97	0.09	3.20	0.10	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	2.66	0.20	2.92	0.09	3.20	0.10	γB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	2.67	0.20	2.92	0.09	3.21	0.10	γB +1SD
	log(K <sub>h</sub> )-1SD	2.75	0.20	2.97	0.09	3.20	0.10	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	2.45	0.20	2.80	0.09	3.20	0.10	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	γ -1SD	2.71	0.18	2.98	0.09	3.22	0.09	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	γ +1SD	2.72	0.22	2.96	0.09	3.18	0.11	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	φ -1SD	2.53	0.18	2.77	0.09	2.98	0.10	log(K <sub>h</sub> )-1SD
2	φ +1SD	2.92	0.21	3.19	0.12	3.44	0.11	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	2.30	0.21	2.66	0.12	3.20	0.11	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	2.64	0.18	2.90	0.09	3.20	0.15	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	2.45	(i)	2.79	(i)	3.20	(i)	
	log(K <sub>h</sub> )+1SD	2.73		2.96		3.20		
	γ -1SD	2.65		2.90		3.13		
	γ +1SD	2.78		3.04		3.26		
	γ -1SD	2.55		2.80		3.01		
	γ +1SD	2.88		3.15		3.40		

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Orting Treatment Plant
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Orting Treatment Plant Levee cross section from STA 4+00. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-2.3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-1	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0	4.62	
2	52.6	1.5	1.5	-2.3	-1	0	0	0	0	0	4.21	
3	62.6	1.5	1.5	-2.3	-1	0	0	0	0	0	5.02	0.80
4	57.6	1	1.5	-2.3	-1	0	0	0	0	0	4.55	
5	57.6	2	1.5	-2.3	-1	0	0	0	0	0	4.67	0.11281
6	57.6	1.5	1	-2.3	-1	0	0	0	0	0	5.07	
7	57.6	1.5	2	-2.3	-1	0	0	0	0	0	4.24	-0.83645
8	57.6	1.5	1.5	-3.3	-1	0	0	0	0	0	5.13	
9	57.6	1.5	1.5	-1.3	-1	0	0	0	0	0	4.35	-0.77407
10	57.6	1.5	1.5	-2.3	-2	0	0	0	0	0	4.34	
11	57.6	1.5	1.5	-2.3	0	0	0	0	0	0	5.22	0.87622
12	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
13	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
14	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
15	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
16	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
17	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
18	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
19	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
20	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
21	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		

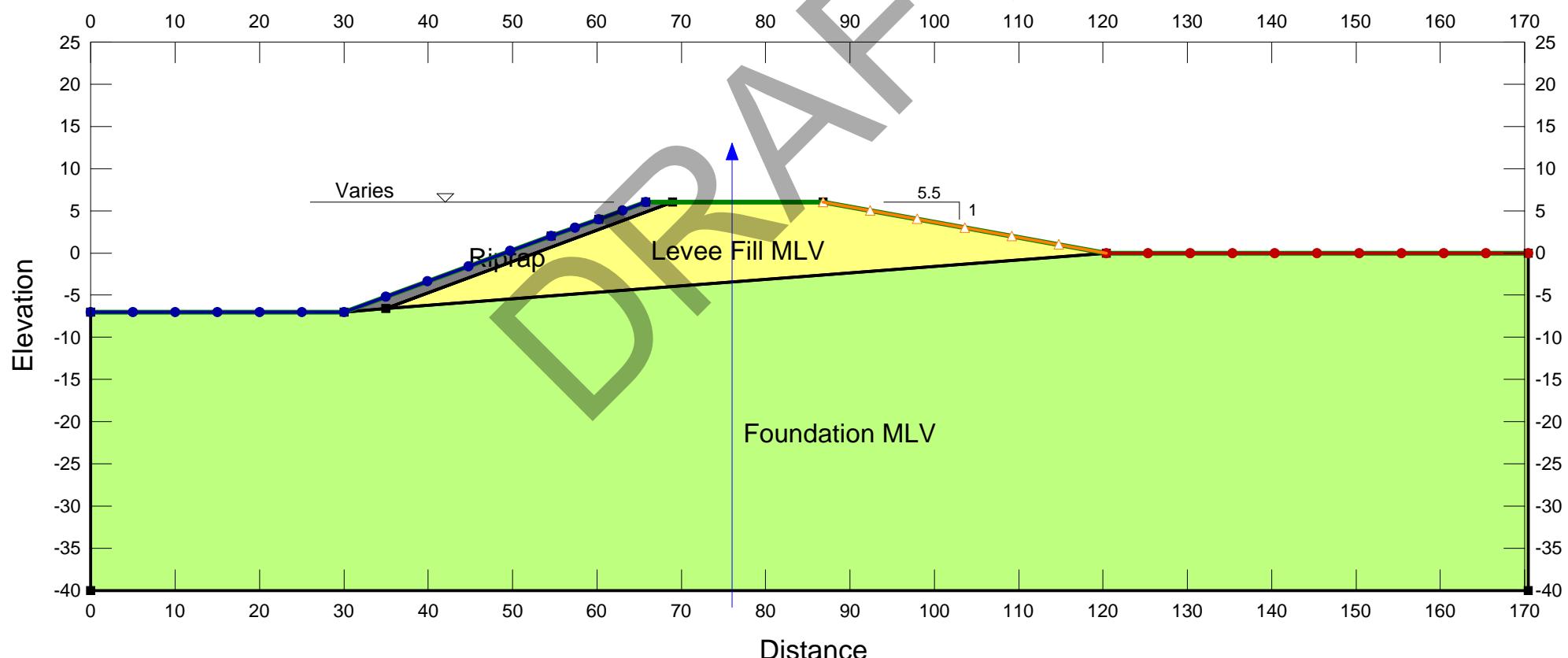
Standard deviation of F,	$\sigma_F$	0.825
Coefficient of variation of F,	$V_F$	0.179
Log normal reliability index,	$\beta_{LN}$	8.537
Reliability		1.000
Probability of failure		0.0E+00

**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 4+00**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

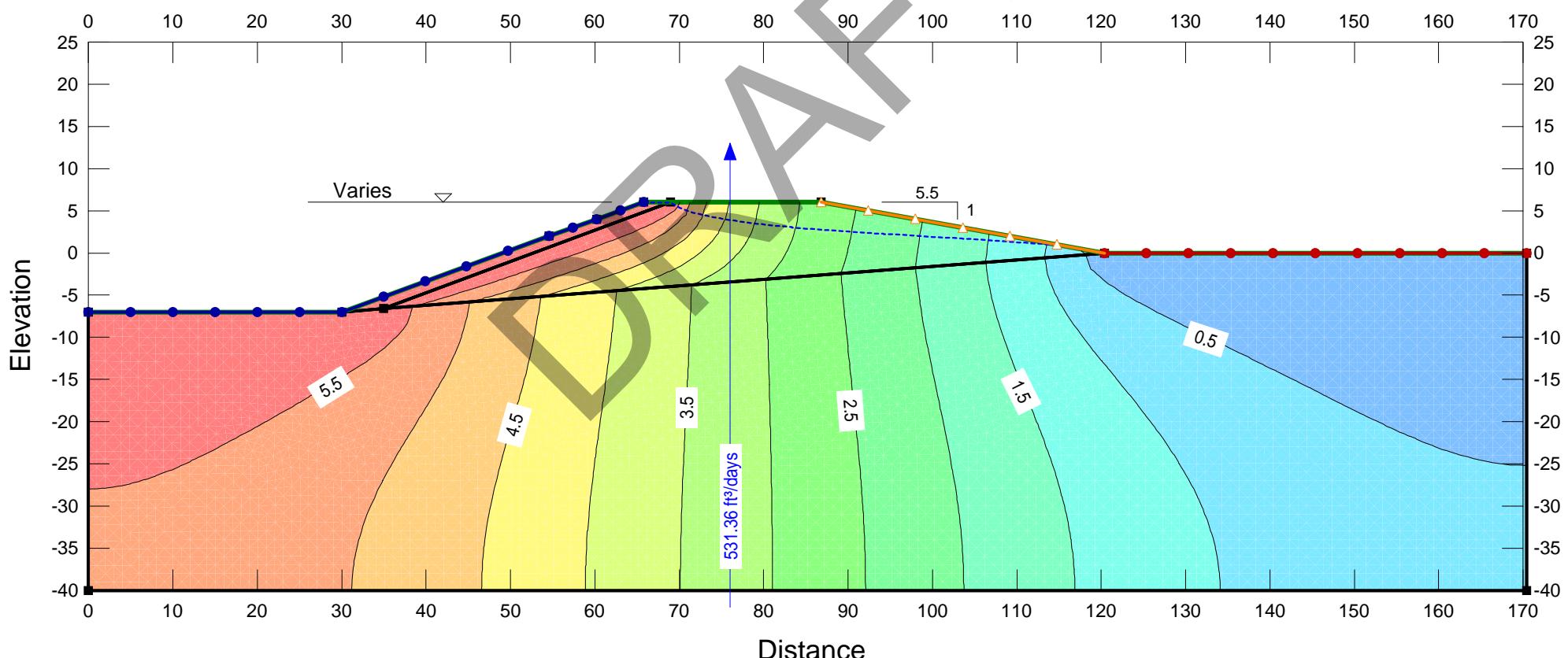


**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 84+12**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

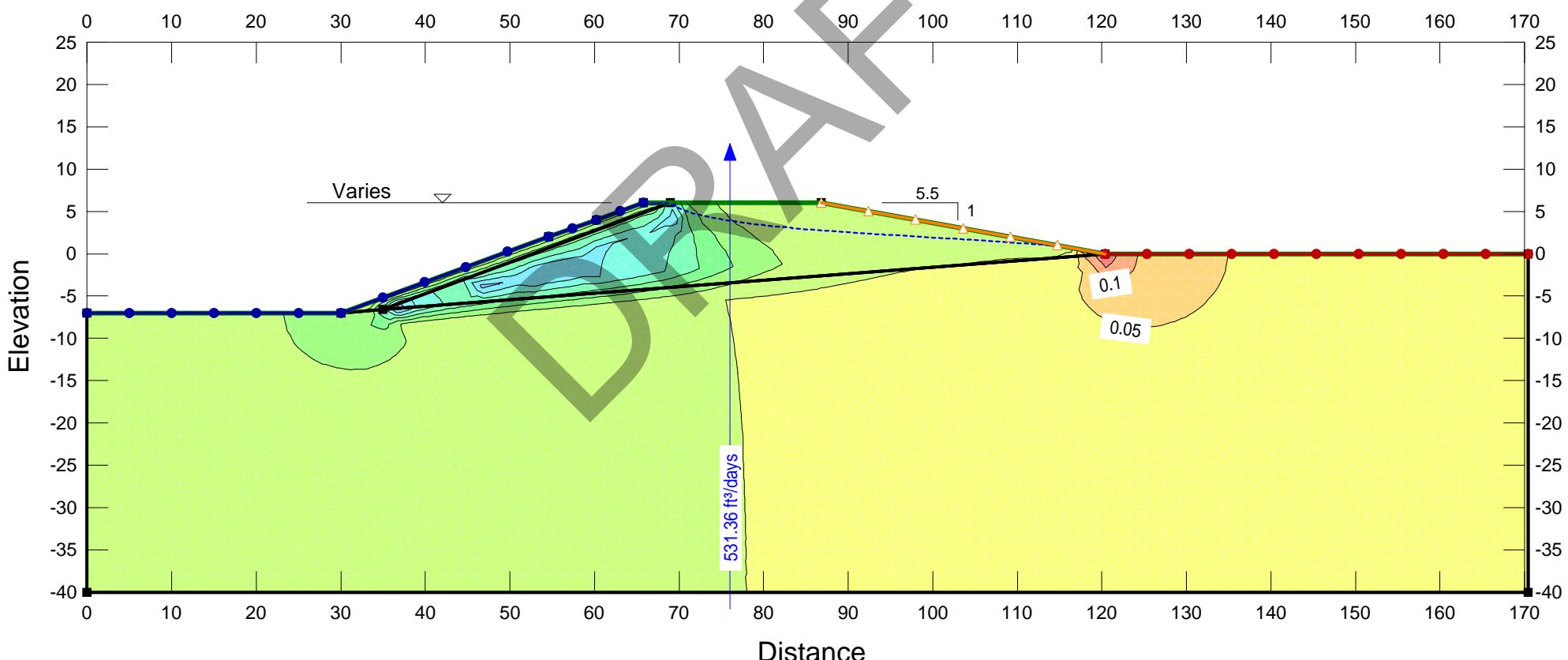


**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 84+12**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)



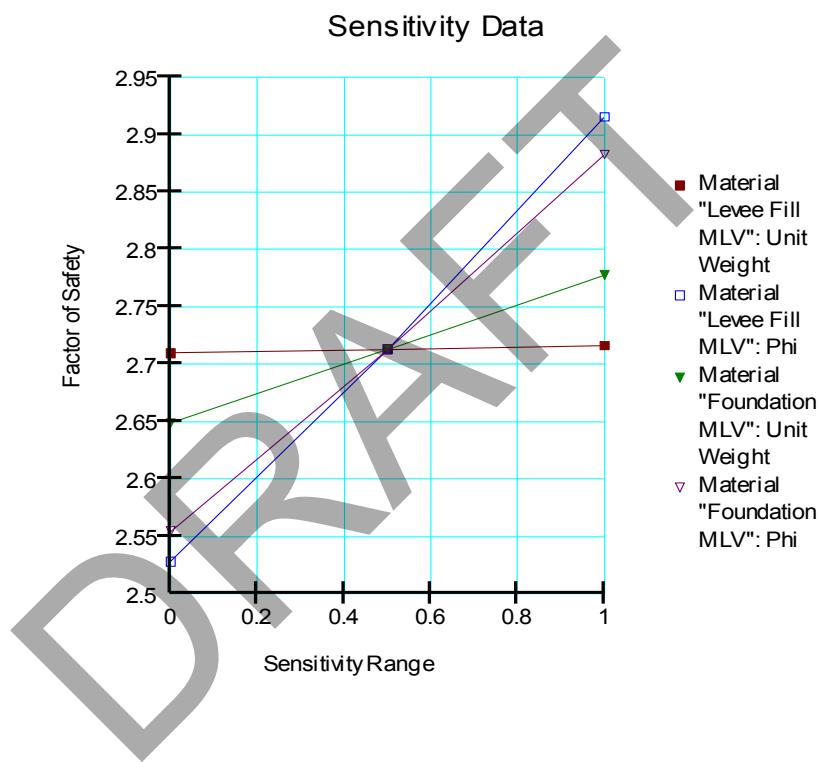
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Orting Treatment Plant
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Orting Treatment Plant Levee cross section from STA 4+00. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-2.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	35	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-2.3	120	33	1.5	-1	120	35	0	0	2.71	
2	1	-2.3	120	33	1.5	-1	120	35	0	0	2.66	
3	2	-2.3	120	33	1.5	-1	120	35	0	0	2.67	0.01
4	1.5	-3.3	120	33	1.5	-1	120	35	0	0	2.75	
5	1.5	-1.3	120	33	1.5	-1	120	35	0	0	2.45	-0.3
6	1.5	-2.3	115	33	1.5	-1	120	35	0	0	2.71	
7	1.5	-2.3	125	33	1.5	-1	120	35	0	0	2.72	0.00648
8	1.5	-2.3	120	30	1.5	-1	120	35	0	0	2.53	
9	1.5	-2.3	120	36	1.5	-1	120	35	0	0	2.92	0.38733
10	1.5	-2.3	120	33	1	-1	120	35	0	0	2.30	
11	1.5	-2.3	120	33	2	-1	120	35	0	0	2.64	0.34
12	1.5	-2.3	120	33	1.5	-2	120	35	0	0	2.45	
13	1.5	-2.3	120	33	1.5	0	120	35	0	0	2.73	0.28
14	1.5	-2.3	120	33	1.5	-1	115	35	0	0	2.65	
15	1.5	-2.3	120	33	1.5	-1	125	35	0	0	2.78	0.12898
16	1.5	-2.3	120	33	1.5	-1	120	32	0	0	2.55	
17	1.5	-2.3	120	33	1.5	-1	120	38	0	0	2.88	0.32848
18	1.5	-2.3	120	33	1.5	-1	120	35	0	0		
19	1.5	-2.3	120	33	1.5	-1	120	35	0	0		0
20	1.5	-2.3	120	33	1.5	-1	120	35	0	0		
21	1.5	-2.3	120	33	1.5	-1	120	35	0	0		0

Standard deviation of F,	$\sigma_F$	0.374
Coefficient of variation of F,	$V_F$	0.138
Log normal reliability index,	$\beta_{LN}$	7.211
Reliability		1.000
Probability of failure		0.000

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	2.7096299	2.5279956	2.6487225	2.5544785
0.5	2.7130198	2.7130198	2.7130198	2.7130198
1	2.7161136	2.9153278	2.7777031	2.8829589

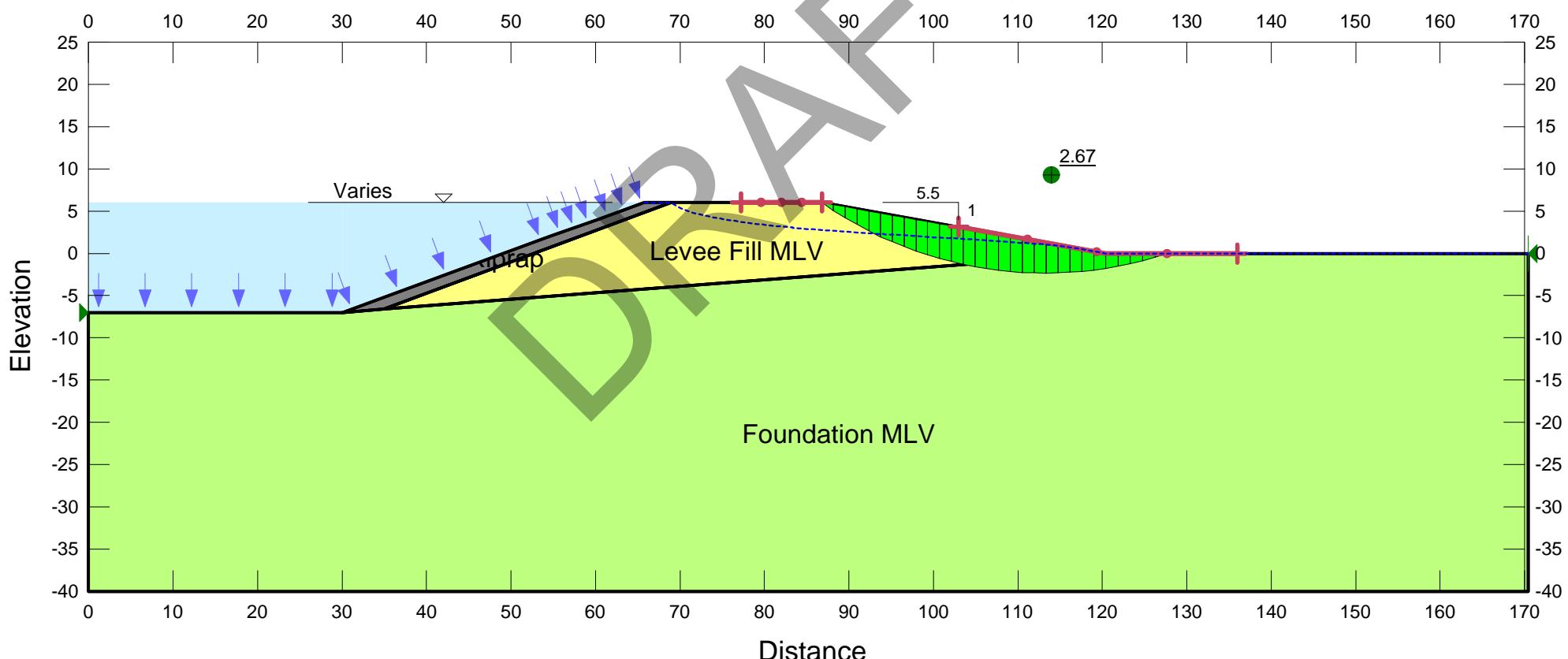


Orting Treatment Plant Levee  
Carbon River  
STA 4+00

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (GP)  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 35 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Orting Treatment Plant
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Orting Treatment Plant Levee cross section from STA 4+00. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-2.3	cm/s	1
5	$\log(K_h)$ (Foundation)	-1	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0	10.26	
2	52.6	1.5	1.5	-2.3	-1	0	0	0	0	0	9.37	
3	62.6	1.5	1.5	-2.3	-1	0	0	0	0	0	11.15	1.78063
4	57.6	1	1.5	-2.3	-1	0	0	0	0	0	10.26	
5	57.6	2	1.5	-2.3	-1	0	0	0	0	0	10.14	-0.11271
6	57.6	1.5	1	-2.3	-1	0	0	0	0	0	10.37	
7	57.6	1.5	2	-2.3	-1	0	0	0	0	0	10.14	-0.22795
8	57.6	1.5	1.5	-3.3	-1	0	0	0	0	0	10.68	
9	57.6	1.5	1.5	-1.3	-1	0	0	0	0	0	7.69	-2.99145
10	57.6	1.5	1.5	-2.3	-2	0	0	0	0	0	7.60	
11	57.6	1.5	1.5	-2.3	0	0	0	0	0	0	10.77	3.16866
12	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
13	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
14	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
15	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
16	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
17	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
18	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
19	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
20	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
21	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		

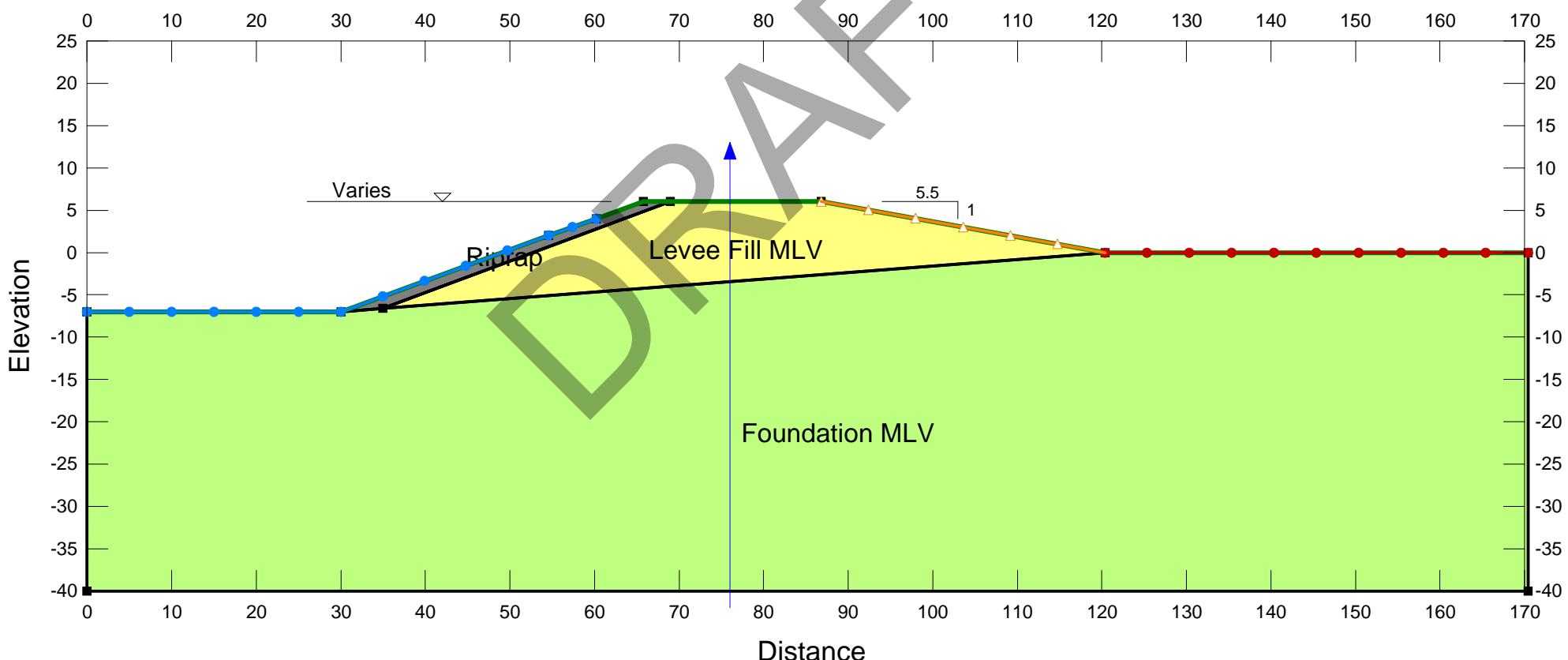
Standard deviation of F,	$\sigma_F$	2.357
Coefficient of variation of F,	$V_F$	0.230
Log normal reliability index,	$\beta_{LN}$	10.147
Reliability		1.000
Probability of failure		0.0E+00

**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 4+00**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

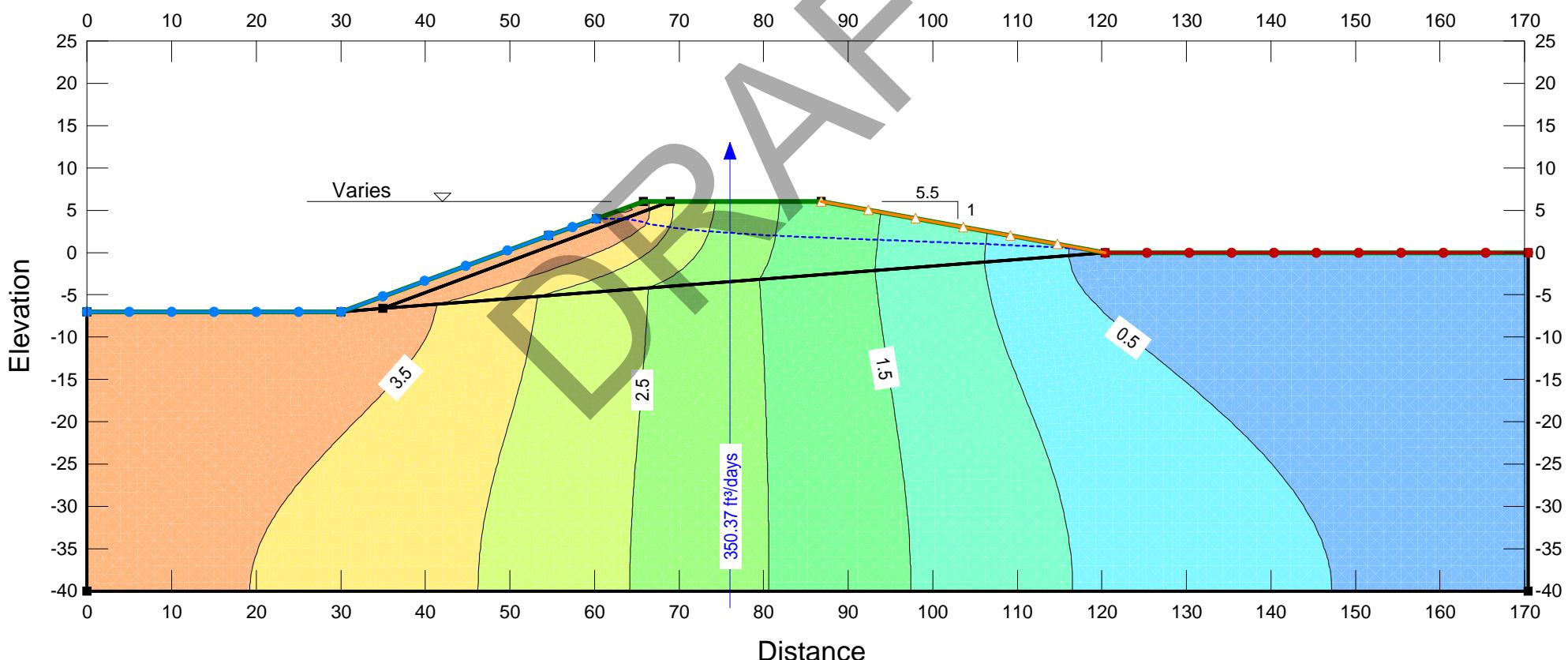


**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 84+12**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

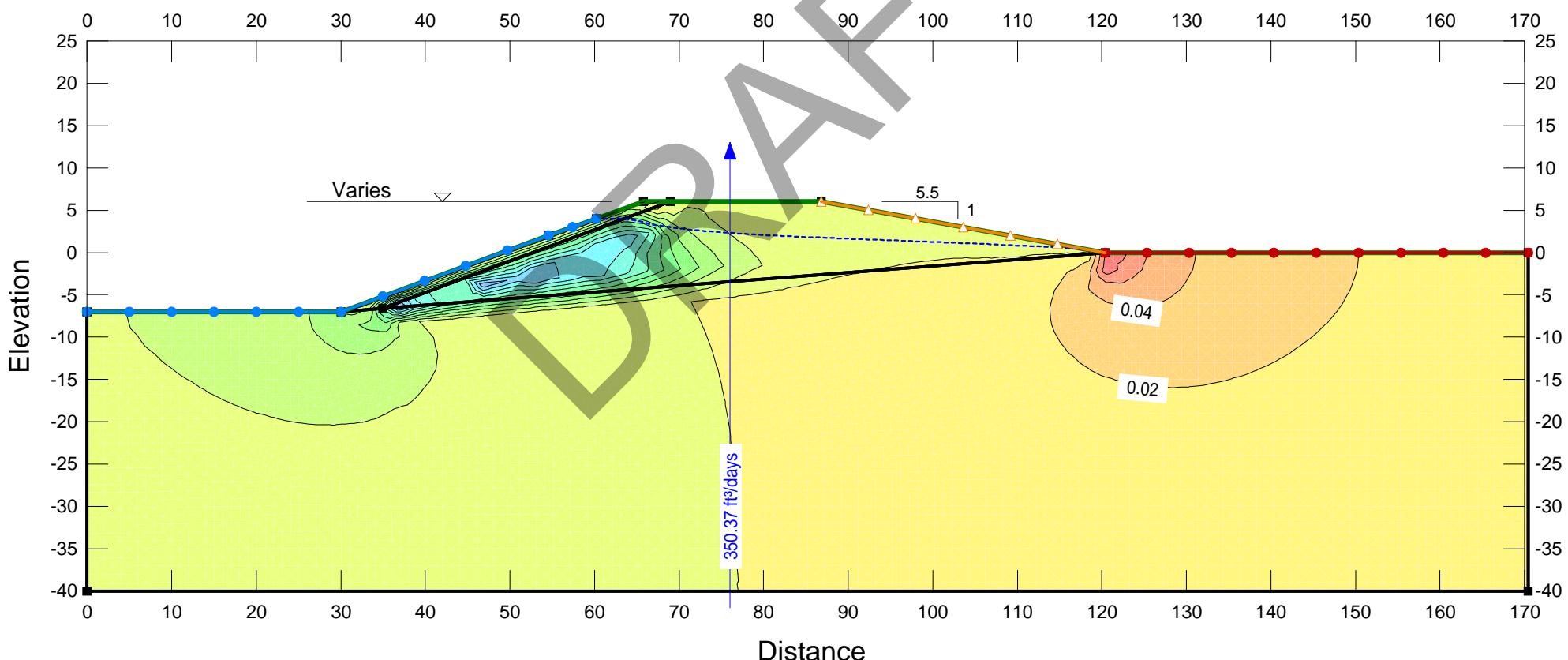


**Orting Treatment Plant Levee  
Carbon River  
STA 84+12**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
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 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)



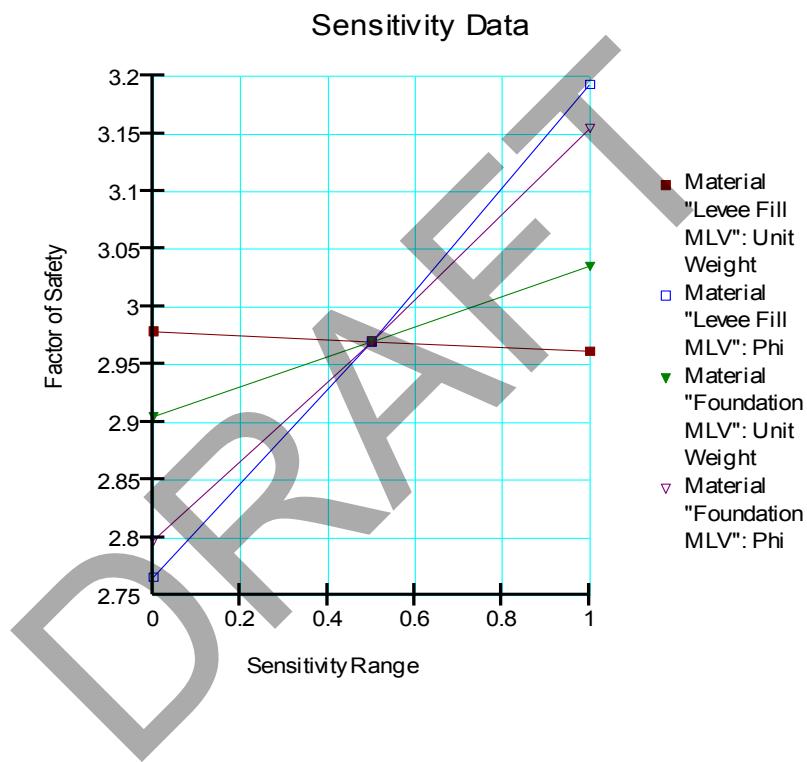
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Orting Treatment Plant
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Orting Treatment Plant Levee cross section from STA 4+00. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-2.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	35	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-2.3	120	33	1.5	-1	120	35	0	0	2.97	
2	1	-2.3	120	33	1.5	-1	120	35	0	0	2.92	
3	2	-2.3	120	33	1.5	-1	120	35	0	0	2.92	0
4	1.5	-3.3	120	33	1.5	-1	120	35	0	0	2.97	
5	1.5	-1.3	120	33	1.5	-1	120	35	0	0	2.80	-0.17
6	1.5	-2.3	115	33	1.5	-1	120	35	0	0	2.98	
7	1.5	-2.3	125	33	1.5	-1	120	35	0	0	2.96	-0.01695
8	1.5	-2.3	120	30	1.5	-1	120	35	0	0	2.77	
9	1.5	-2.3	120	36	1.5	-1	120	35	0	0	3.19	0.42677
10	1.5	-2.3	120	33	1	-1	120	35	0	0	2.66	
11	1.5	-2.3	120	33	2	-1	120	35	0	0	2.90	0.24
12	1.5	-2.3	120	33	1.5	-2	120	35	0	0	2.79	
13	1.5	-2.3	120	33	1.5	0	120	35	0	0	2.96	0.17
14	1.5	-2.3	120	33	1.5	-1	115	35	0	0	2.90	
15	1.5	-2.3	120	33	1.5	-1	125	35	0	0	3.04	0.13057
16	1.5	-2.3	120	33	1.5	-1	120	32	0	0	2.80	
17	1.5	-2.3	120	33	1.5	-1	120	38	0	0	3.15	0.35752
18	1.5	-2.3	120	33	1.5	-1	120	35	0	0		
19	1.5	-2.3	120	33	1.5	-1	120	35	0	0		0
20	1.5	-2.3	120	33	1.5	-1	120	35	0	0		
21	1.5	-2.3	120	33	1.5	-1	120	35	0	0		0

Standard deviation of F,	$\sigma_F$	0.333
Coefficient of variation of F,	$V_F$	0.112
Log normal reliability index,	$\beta_{LN}$	9.693
Reliability		1.000
Probability of failure		0.000

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	2.978883	2.7662066	2.9049484	2.7974762
0.5	2.9700237	2.9700237	2.9700237	2.9700237
1	2.9619346	3.1929779	3.0355166	3.1549983

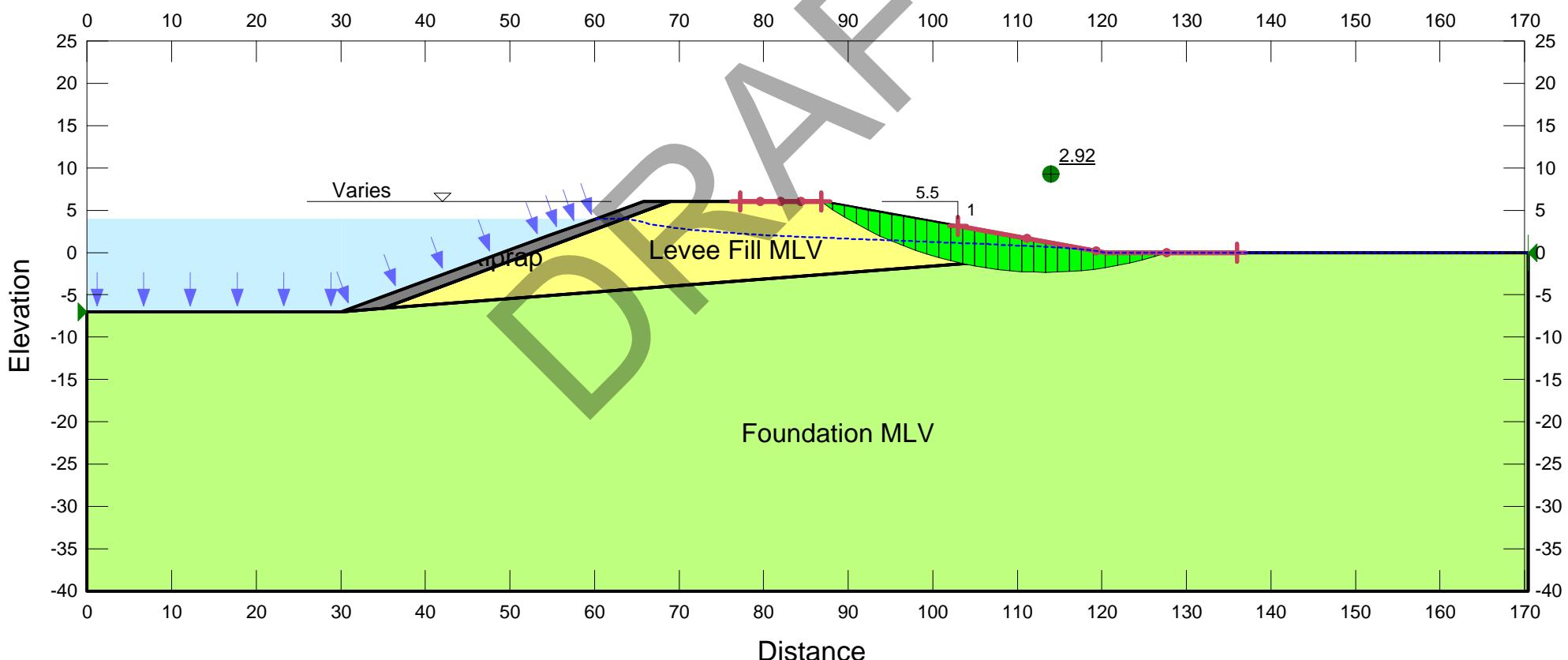


**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 4+00**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Orting Treatment Plant
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Orting Treatment Plant Levee cross section from STA 4+00. Water Surface Elevation is 4 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-2.3	cm/s	1
5	$\log(K_h)$ (Foundation)	-1	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0	8.88	
2	52.6	1.5	1.5	-2.3	-1	0	0	0	0	0	8.11	
3	62.6	1.5	1.5	-2.3	-1	0	0	0	0	0	9.65	1.54093
4	57.6	1	1.5	-2.3	-1	0	0	0	0	0	8.88	
5	57.6	2	1.5	-2.3	-1	0	0	0	0	0	8.88	0
6	57.6	1.5	1	-2.3	-1	0	0	0	0	0	10.14	
7	57.6	1.5	2	-2.3	-1	0	0	0	0	0	8.05	-2.08893
8	57.6	1.5	1.5	-3.3	-1	0	0	0	0	0	8.89	
9	57.6	1.5	1.5	-1.3	-1	0	0	0	0	0	8.67	-0.22545
10	57.6	1.5	1.5	-2.3	-2	0	0	0	0	0	8.66	
11	57.6	1.5	1.5	-2.3	0	0	0	0	0	0	6.03	-2.63395
12	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
13	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
14	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
15	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
16	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
17	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
18	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
19	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
20	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		
21	57.6	1.5	1.5	-2.3	-1	0	0	0	0	0		

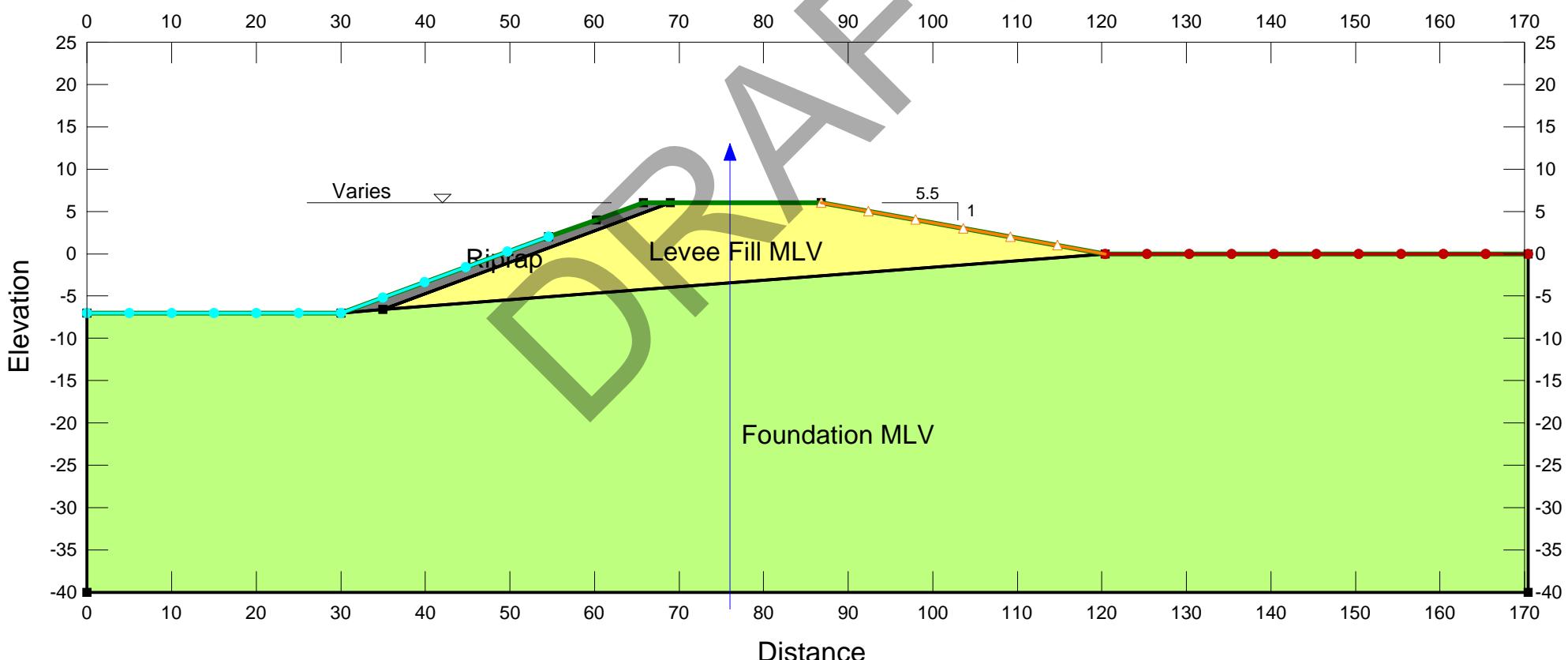
Standard deviation of F,	$\sigma_F$	1.852
Coefficient of variation of F,	$V_F$	0.209
Log normal reliability index,	$\beta_{LN}$	10.470
Reliability		1.000
Probability of failure		0.0E+00

**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 4+00**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

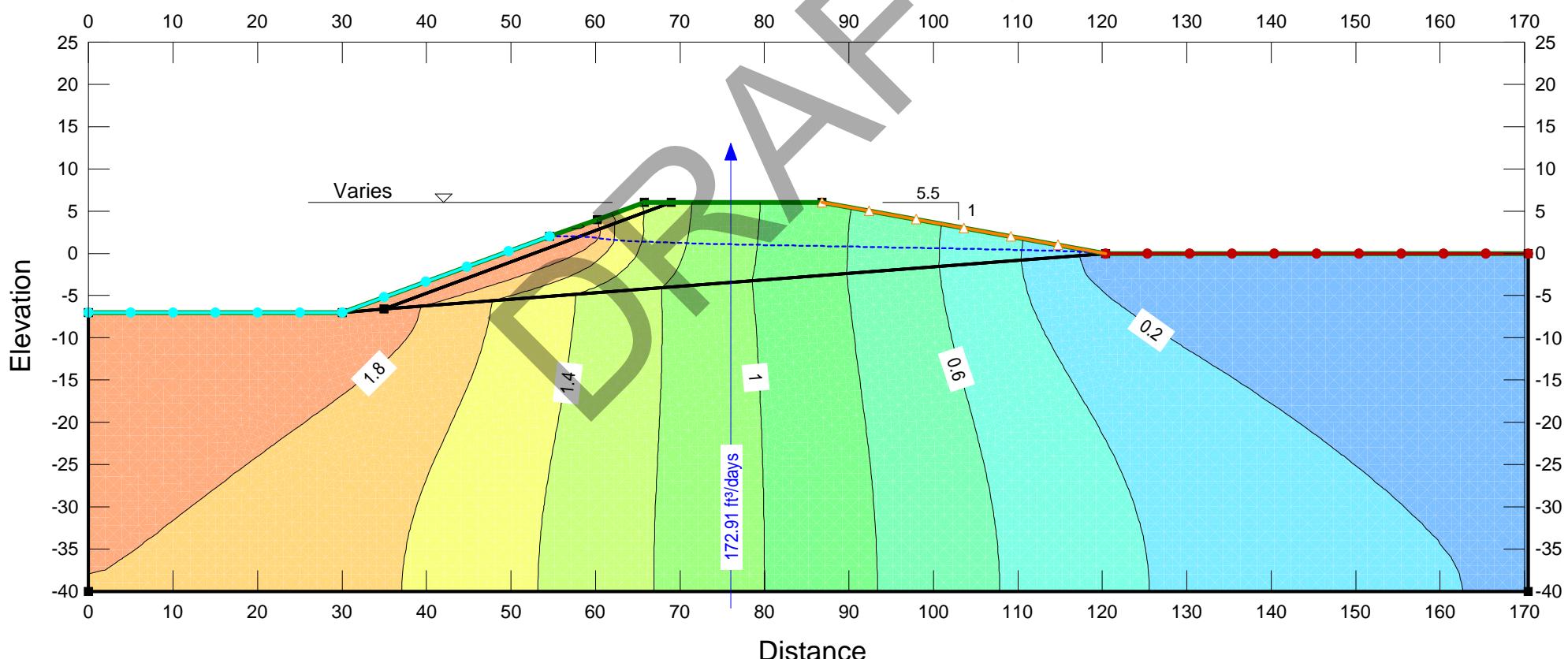


**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 84+12**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

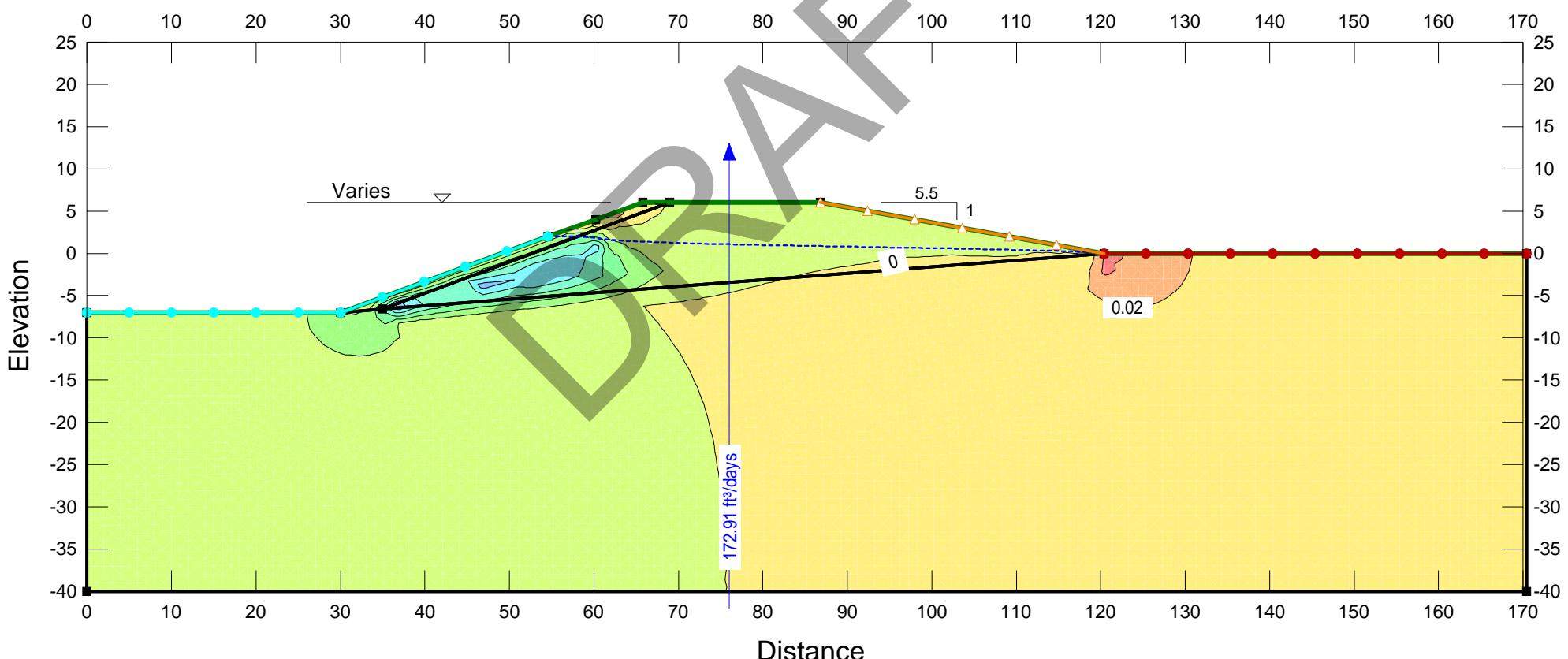


**Orting Treatment Plant Levee**  
**Carbon River**  
**STA 84+12**

**Levee Fill (SP-SM)**  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
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 Unit Weight: 120 pcf (+/- 5)  
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 KH/KV Ratio: 1.0  
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**Levee Foundation (GP)**  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
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**Taylor's series method spreadsheet**

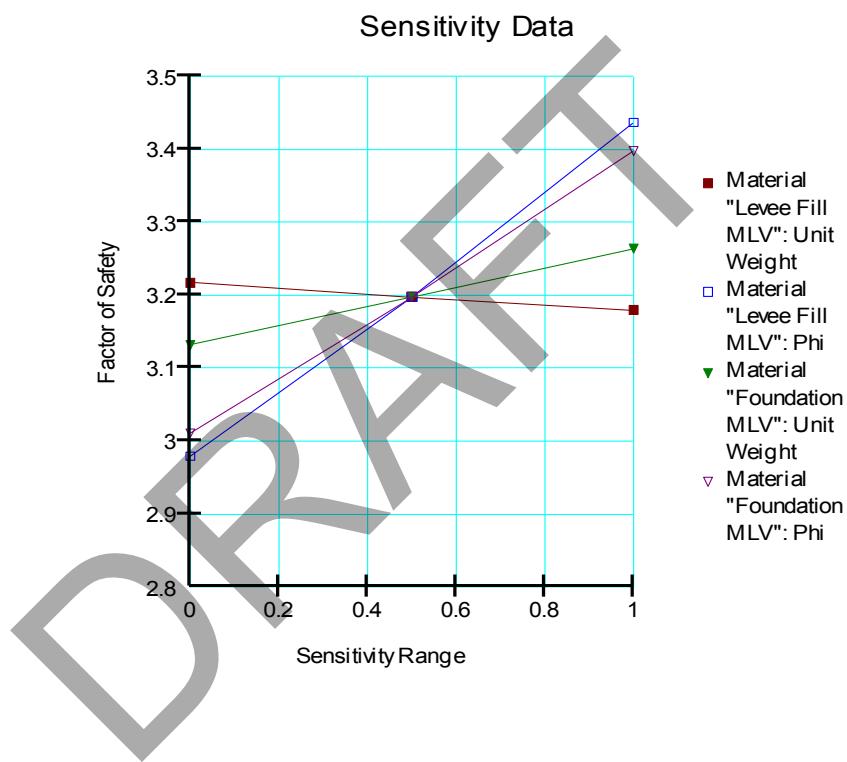
Project	Puyallup General Investigation
Feature	Orting Treatment Plant
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Orting Treatment Plant Levee cross section from STA 4+00. Water Surface Elevation is 4 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-2.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	35	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-2.3	120	33	1.5	-1	120	35	0	0	3.20	
2	1	-2.3	120	33	1.5	-1	120	35	0	0	3.20	
3	2	-2.3	120	33	1.5	-1	120	35	0	0	3.21	0.01
4	1.5	-3.3	120	33	1.5	-1	120	35	0	0	3.20	
5	1.5	-1.3	120	33	1.5	-1	120	35	0	0	3.20	0
6	1.5	-2.3	115	33	1.5	-1	120	35	0	0	3.22	
7	1.5	-2.3	125	33	1.5	-1	120	35	0	0	3.18	-0.0377
8	1.5	-2.3	120	30	1.5	-1	120	35	0	0	2.98	
9	1.5	-2.3	120	36	1.5	-1	120	35	0	0	3.44	0.45715
10	1.5	-2.3	120	33	1	-1	120	35	0	0	3.20	
11	1.5	-2.3	120	33	2	-1	120	35	0	0	3.20	0
12	1.5	-2.3	120	33	1.5	-2	120	35	0	0	3.20	
13	1.5	-2.3	120	33	1.5	0	120	35	0	0	3.20	0
14	1.5	-2.3	120	33	1.5	-1	115	35	0	0	3.13	
15	1.5	-2.3	120	33	1.5	-1	125	35	0	0	3.26	0.132
16	1.5	-2.3	120	33	1.5	-1	120	32	0	0	3.01	
17	1.5	-2.3	120	33	1.5	-1	120	38	0	0	3.40	0.38653
18	1.5	-2.3	120	33	1.5	-1	120	35	0	0		
19	1.5	-2.3	120	33	1.5	-1	120	35	0	0		0
20	1.5	-2.3	120	33	1.5	-1	120	35	0	0		
21	1.5	-2.3	120	33	1.5	-1	120	35	0	0		0

Standard deviation of F,	$\sigma_F$	0.307
Coefficient of variation of F,	$V_F$	0.096
Log normal reliability index,	$\beta_{LN}$	12.081
Reliability		1.000
Probability of failure		0.0E+00

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	3.2172138	2.9791888	3.1317294	3.0110067
0.5	3.1975071	3.1975071	3.1975071	3.1975071
1	3.1795163	3.4363375	3.2637263	3.3975363

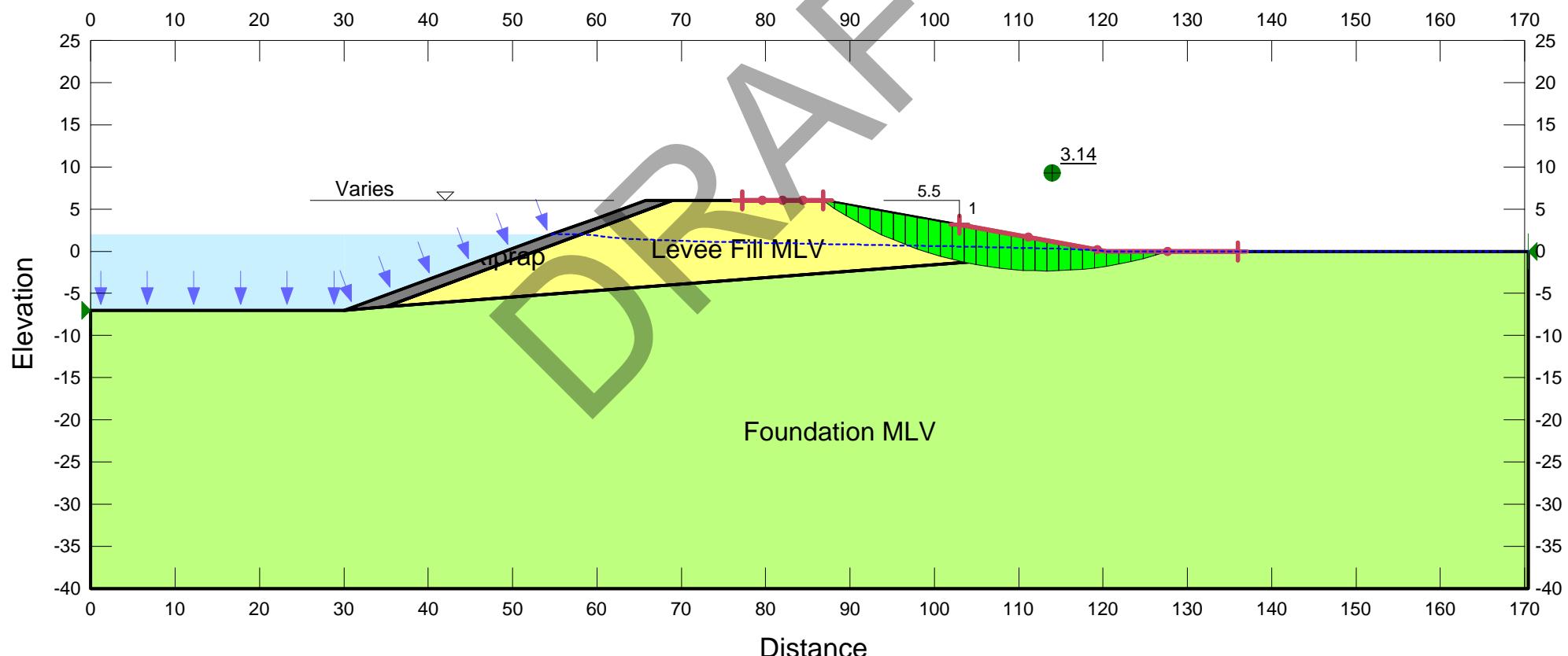


Orting Treatment Plant Levee  
Carbon River  
STA 4+00

Levee Fill (SP-SM)  
 $\log(K\text{-Sat})$ : -2.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (GP)  
 $\log(K\text{-Sat})$ : -1 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 35 degs (+/- 3)



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

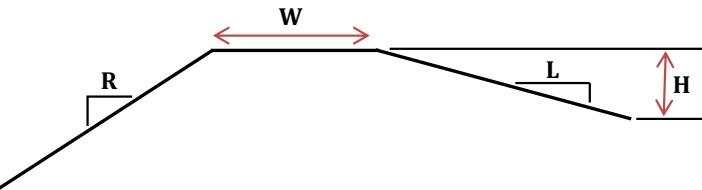
Location:	Pierce County, Washington
River:	White River
Levee Segment Name:	Potelco
Station:	30+00

#### Levee Condition Factor

Levee Condition Factor	2
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**Remarks:** Levee is deemed a 2 because the levee is unacceptably maintained per USACE guidance. Vegetation, rutting, poor sod cover, and erosion were noted.

#### Levee Geometry



Crown Width (W)	6 Feet
Landward Levee Height (H)	2 Feet
Riverward Slope (R)	1.4 H:1V
Landward Slope (L)	7.5 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	2 Feet
Breach Width at Top of Levee	44.8 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.39 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

	Homogeneous Foundation
	Interbedded Foundation
X	Layered Foundation

**Remarks:** Levee foundation is layered with a medium dense SAND with silt (SP-SM) alluvium. Lenses 1 to 2 inches thick.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
Loose / Soft		Low
Medium		Medium
X Dense / Stiff	X	High

**Remarks:** Levee embankment material is medium dense to dense poorly graded GRAVEL (GP).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
68.45	1.00
68.45	0.12
67.45	0.07
66.45	0.05
66.45	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

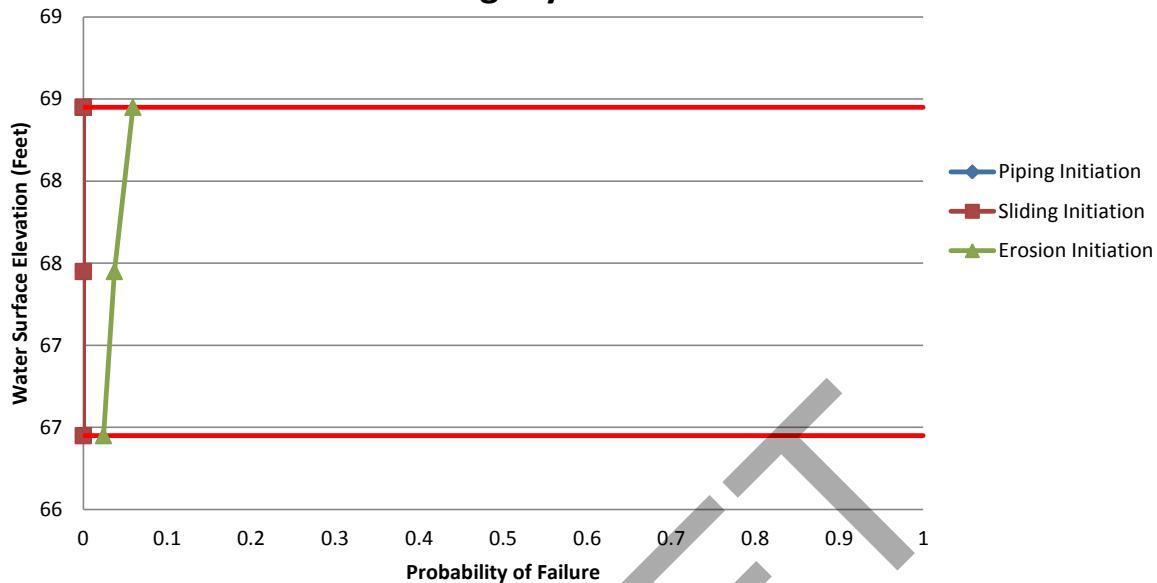
Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

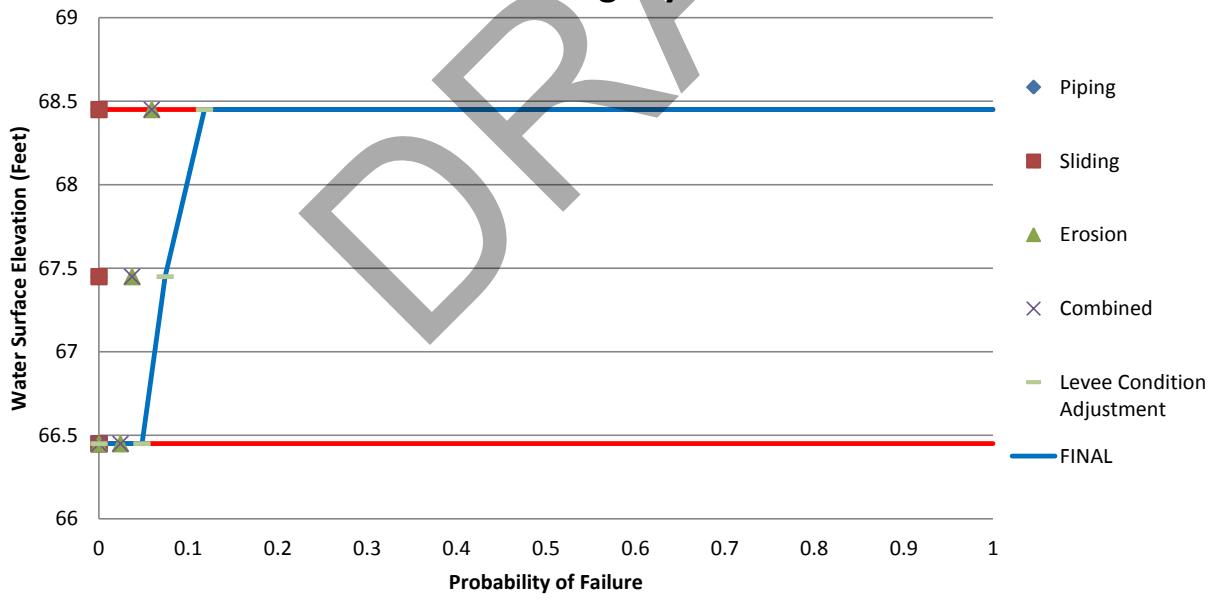
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks: Fragility curve above displays the fragility curve at initiation only. No adjustments.*

### Levee Fragility Curve



*Remarks: The final levee fragility curve for the Potelco Levee is only accounting unique erosion computational values for probability of failure. Engineering judgment was used based on the geometry of the levee prism to conclude probability of failure for sliding and piping are essentially zero.*

# Potelco Levee - White River



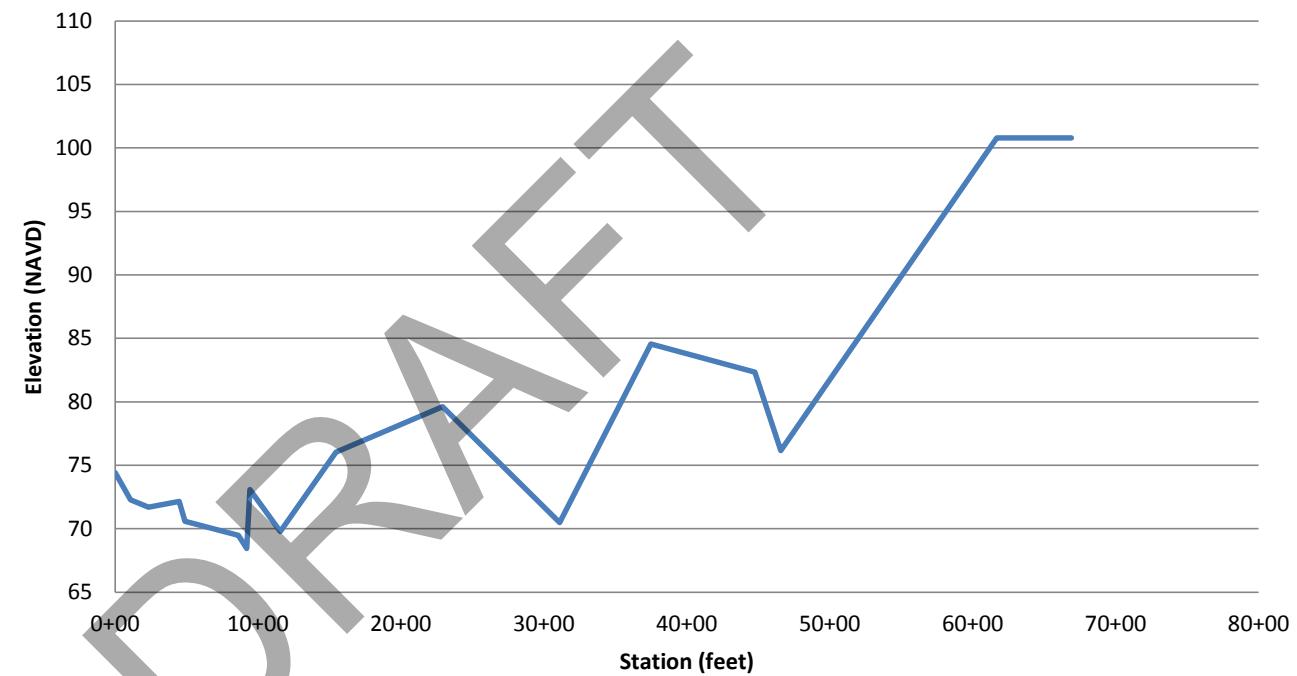
**Potelco Levee**

**White River**

<b>Min</b>	68.45
<b>Max</b>	100.78

<b>Station Begin</b>	0+00
<b>Station End</b>	66+91

**Levee Profile**



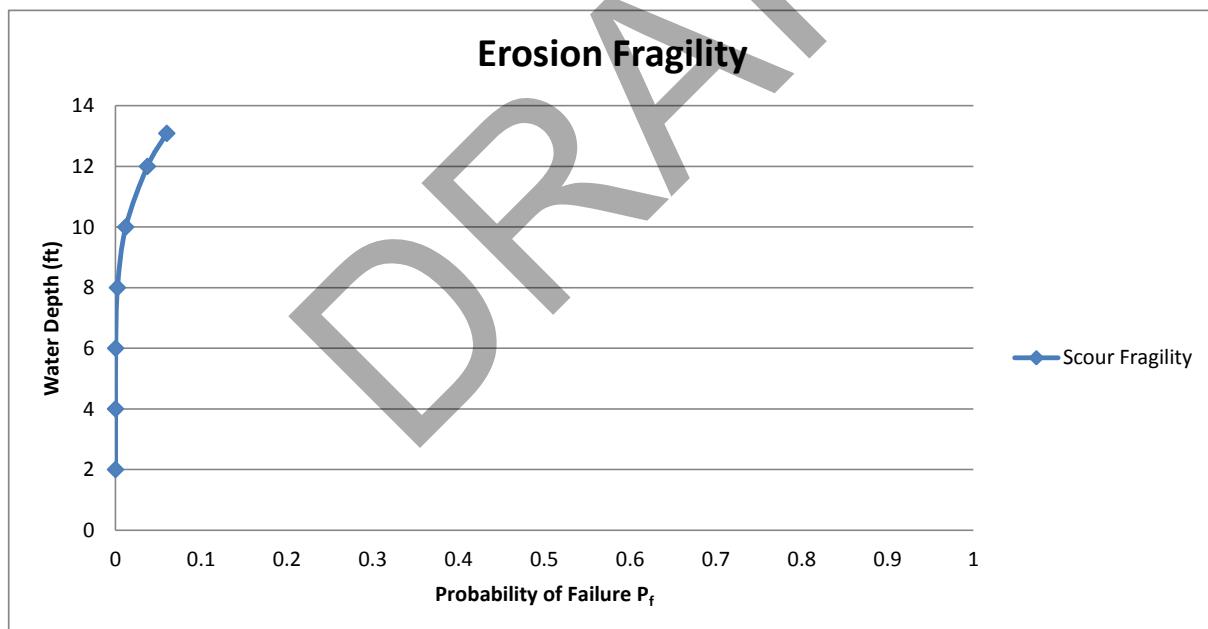
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Potelco Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.00272	CV(s) =	0.1	0.000272
Manning's "n"	n =	0.045	CV(n) =	0.15	0.00675
Scouring Velocity		V <sub>crit</sub> =	14.23		2.85
			CV(v <sub>crit</sub> )	0.2	

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	2.734	0.1581139		-1.649388421	0.254950976	-6.46943	4.9185E-11
4	4.340	0.1581139		-1.187290301	0.254950976	-4.65694	1.6048E-06
6	5.687	0.1581139		-0.916980229	0.254950976	-3.59669	0.00016114
8	6.889	0.1581139		-0.725192181	0.254950976	-2.84444	0.00222449
10	7.994	0.1581139		-0.576429813	0.254950976	-2.26094	0.01188137
12	9.027	0.1581139		-0.454882109	0.254950976	-1.78419	0.03719604
13.09	9.566	0.1581139		-0.396920822	0.254950976	-1.55685	0.05975287



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Puyallup Authorized Right Bank Reference Section & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	Puyallup Authorized Left Bank
<b>Station:</b>	71+00

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is acceptable per USACE guidance. No maintenance issues were noted.

#### Levee Geometry

Crown Width (W)	15 Feet
Landward Levee Height (H)	9 Feet
Riverward Slope (R)	2.2 H:1V
Landward Slope (L)	3.4 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	9 Feet
Breach Width at Top of Levee	202 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.75 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

	Homogeneous Foundation
	Interbedded Foundation
X	Layered Foundation

**Remarks:** Levee foundation is a medium stiff low plasticity SILT (ML).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )	
	Loose / Soft		Low
X	Medium	X	Medium
	Dense / Stiff		High

**Remarks:** Levee embankment material is a medium dense silty SAND with gravel (SM).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
16.52	1.00
16.52	0.42
13.52	0.07
10.52	0.03
7.52	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

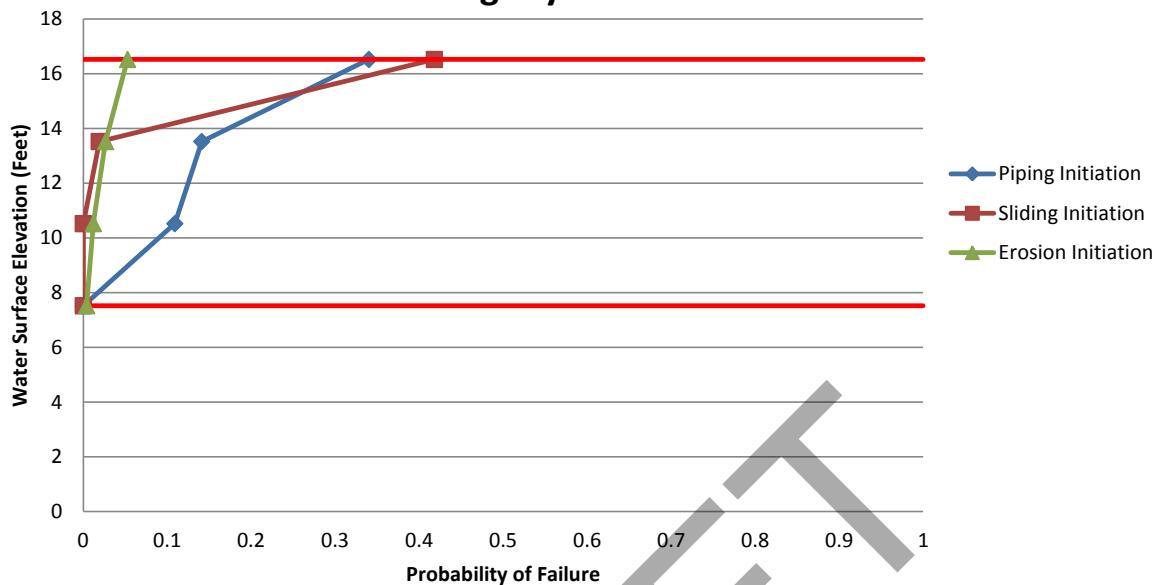
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

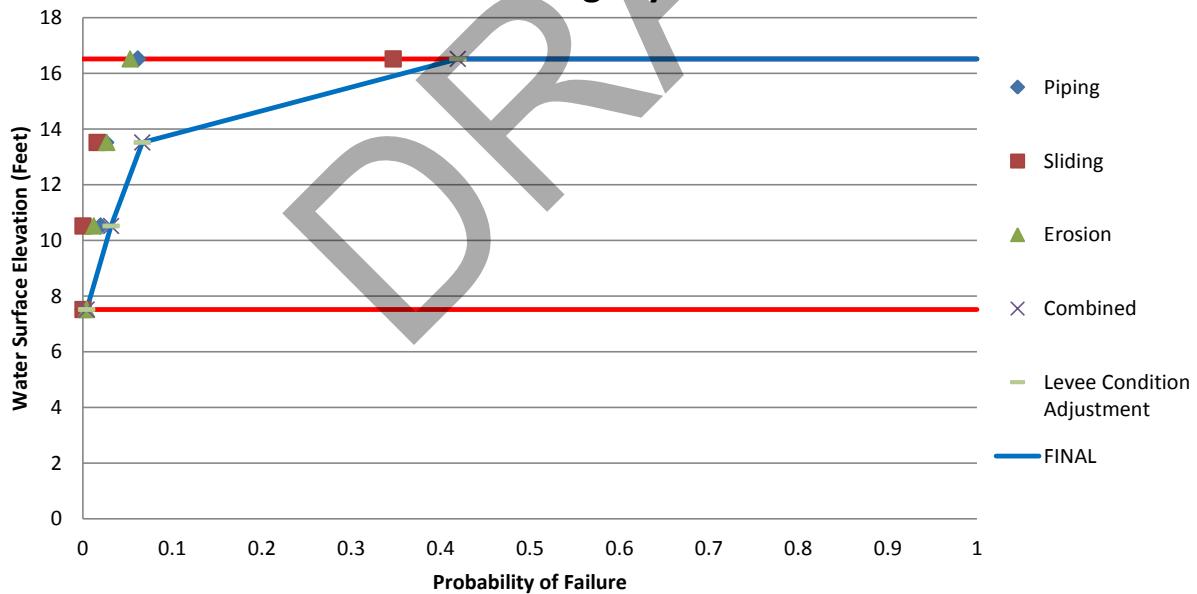
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Puyallup Authorized Left Bank Levee was chosen to mimic that of the Puyallup Authorized Right Bank. Geometry and construction techniques are very similar and therefore the fragility curve is similar.

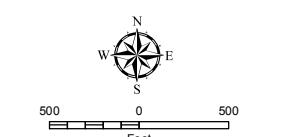
# Puyallup Left Bank Levee - Puyallup River



Legend

- Potential Failure Point
- ◆ 2011 USACE Boring
- H&H Levee Breach Locations
- + River Mileposts
- Levee Station
- Levee Centerline

Location Map



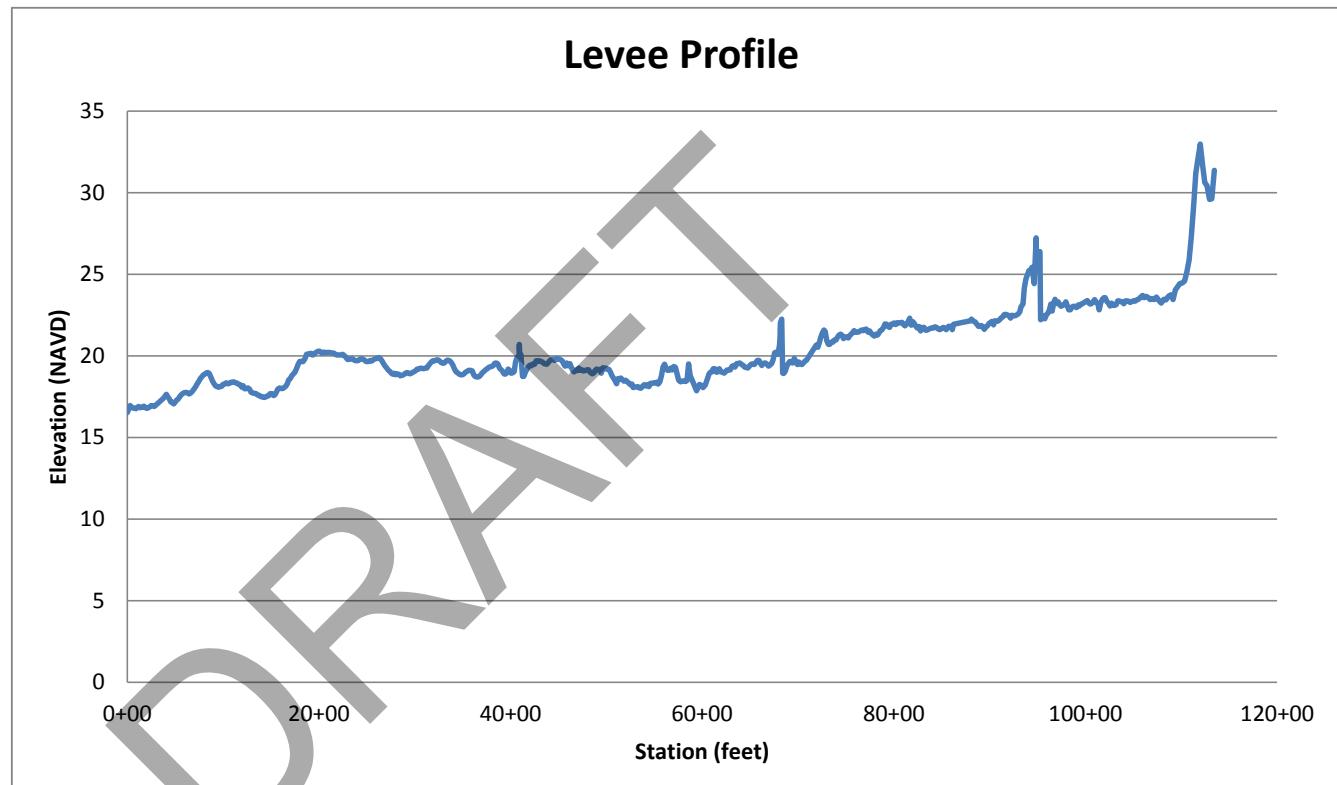
**DISCLAIMER:** While the United States Army Corps of Engineers, (hereinafter referred to as USACE), has made a reasonable effort to insure the accuracy of the maps and associated data, it should be explicitly noted that USACE makes no warranty, representation or guarantee, expressed or implied, as to the absolute, semi-absolute, accuracy, timeliness or completeness of any of the data provided herein. The USACE, its officers, agents, employees, or servants shall assume no liability of any nature for any errors, omissions, or inaccuracies in the information provided regardless of how caused. The USACE, its officers, agents, employees or servants shall assume no liability for any damages resulting from the use of the maps and associated data if the user of the maps and associated data in reliance upon any information or data furnished here by. By using these maps and associated data the user does so entirely at their own risk and explicitly acknowledges that he/she is aware of and agrees to be bound by this disclaimer and agrees not to present any claim or demands of any nature against the USACE, its officers, agents, employees or servants in any forum whatsoever for any damages of any nature whatsoever that may result from or may be caused in any way by the use of the maps and associated data.

## *Puyallup Authorized Levee Left Bank*

*Puyallup River*

<b>Min</b>	16.52
<b>Max</b>	32.98

<b>Station Begin</b>	0+00
<b>Station End</b>	113+44

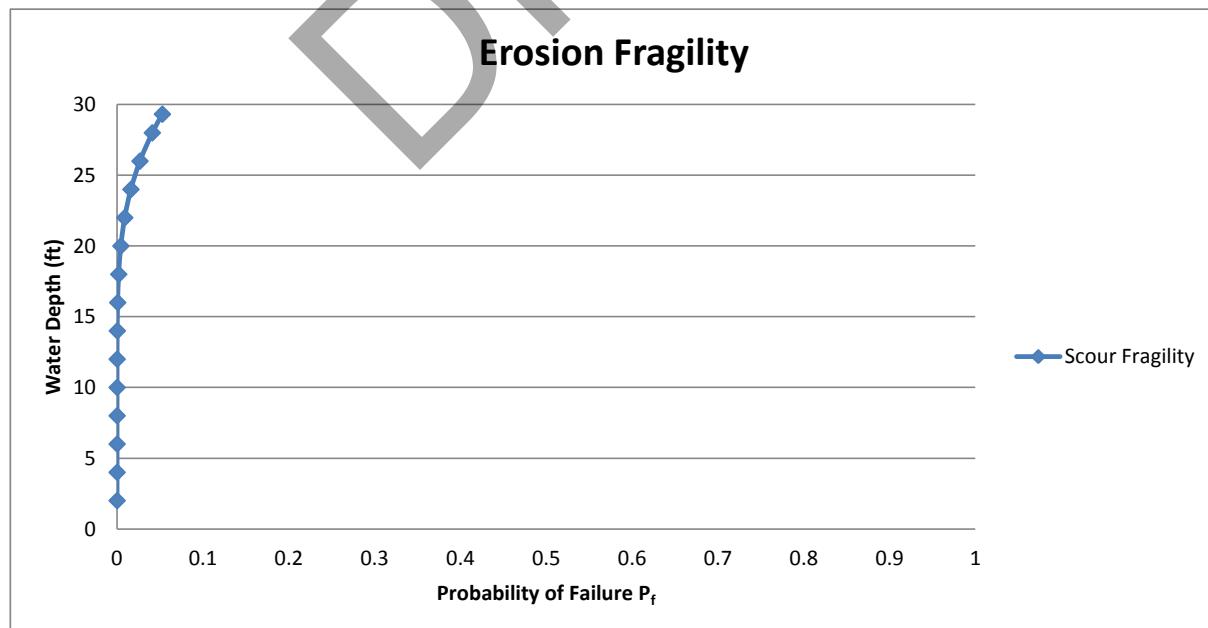


## Surface Erosion Analysis

### Puyallup Authorized Left Bank Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.00034	CV(s) =	0.1	0.000034
Manning's "n"	n =	0.035	CV(n) =	0.15	0.00525
Scouring Velocity	$V_{crit} =$	11.25	$CV(V_{crit})$	0.2	2.25

Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	1.243	0.1581139		-2.202792949	0.254950976	-8.64006	2.8091E-18
4	1.973	0.1581139		-1.740694829	0.254950976	-6.82757	4.3183E-12
6	2.585	0.1581139		-1.470384757	0.254950976	-5.76732	4.027E-09
8	3.131	0.1581139		-1.278596709	0.254950976	-5.01507	2.6507E-07
10	3.634	0.1581139		-1.129834341	0.254950976	-4.43157	4.6774E-06
12	4.103	0.1581139		-1.008286636	0.254950976	-3.95483	3.8295E-05
14	4.548	0.1581139		-0.905519517	0.254950976	-3.55174	0.00019135
16	4.971	0.1581139		-0.816498588	0.254950976	-3.20257	0.00068103
18	5.377	0.1581139		-0.737976564	0.254950976	-2.89458	0.00189832
20	5.768	0.1581139		-0.667736221	0.254950976	-2.61908	0.0044084
22	6.147	0.1581139		-0.604196101	0.254950976	-2.36985	0.0088976
24	6.514	0.1581139		-0.546188516	0.254950976	-2.14233	0.01608356
26	6.871	0.1581139		-0.492826711	0.254950976	-1.93303	0.02661653
28	7.219	0.1581139		-0.443421396	0.254950976	-1.73924	0.04099612
29.32	7.444	0.1581139		-0.412711152	0.254950976	-1.61879	0.05274662



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Puyallup Authorized Right Bank Cross Section Model & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	Puyallup Authorized Right Bank
<b>Station:</b>	85+04

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is acceptable per USACE guidance. No maintenance issues were noted.

#### Levee Geometry

Crown Width (W)	15 Feet
Landward Levee Height (H)	9 Feet
Riverward Slope (R)	2.4 H:1V
Landward Slope (L)	3.4 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	9 Feet
Breach Width at Top of Levee	202 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.75 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

	Homogeneous Foundation
	Interbedded Foundation
X	Layered Foundation

**Remarks:** Levee foundation is a medium stiff low plasticity SILT (ML).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )	
	Loose / Soft		Low
X	Medium	X	Medium
	Dense / Stiff		High

**Remarks:** Levee embankment material is a medium dense silty SAND with gravel (SM).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
15.49	1.00
15.49	0.42
12.49	0.07
9.49	0.03
6.49	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

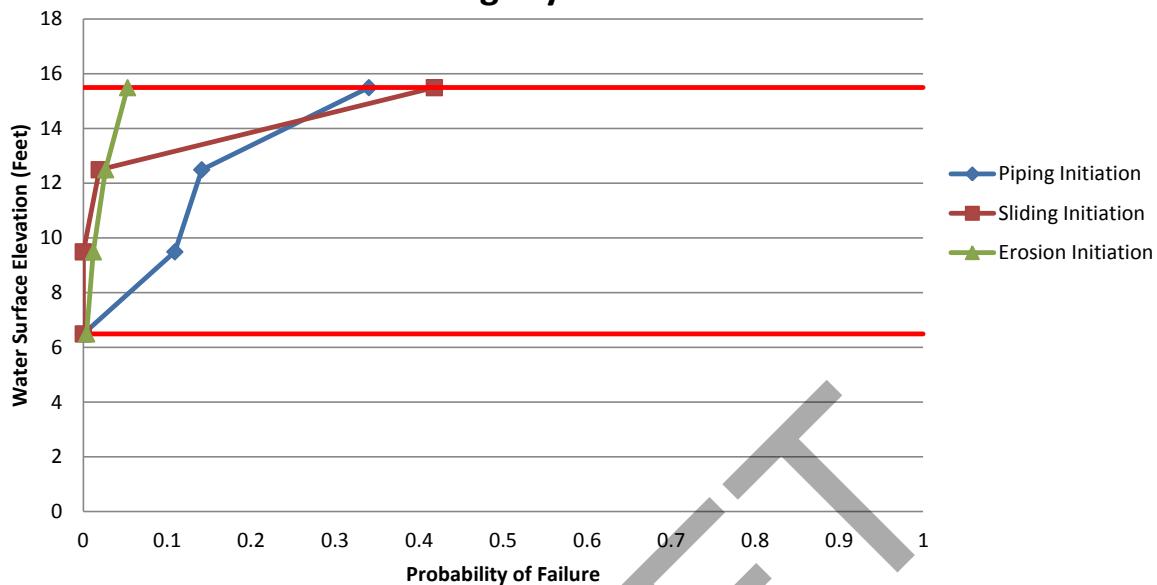
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

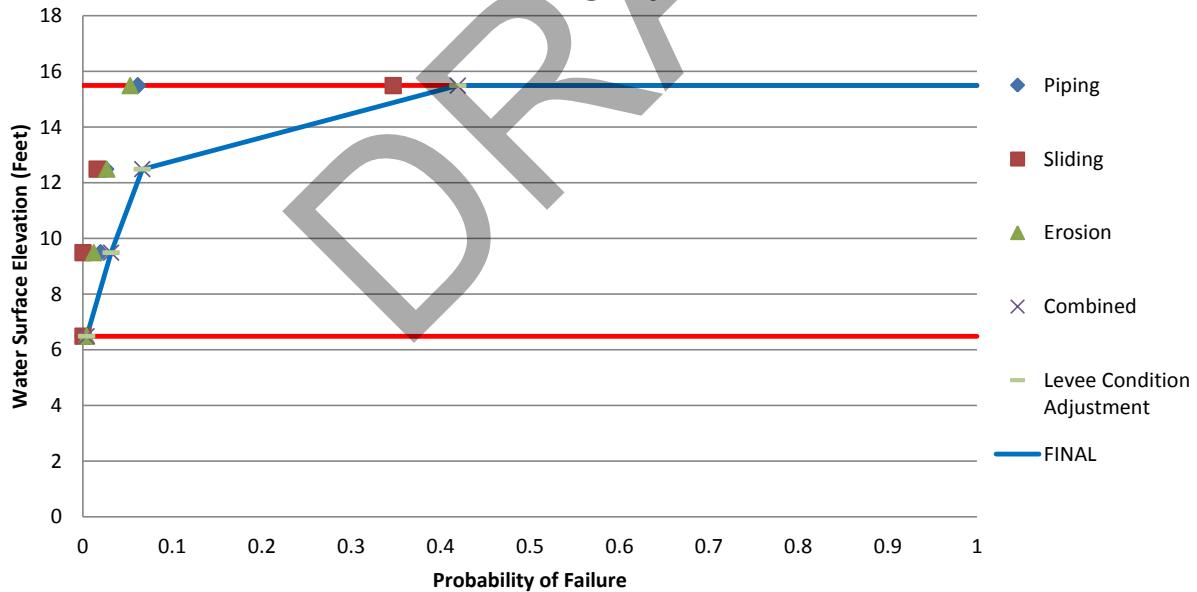
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Puyallup Authorized Right Bank Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# Puyallup Right Bank Levee - Puyallup River

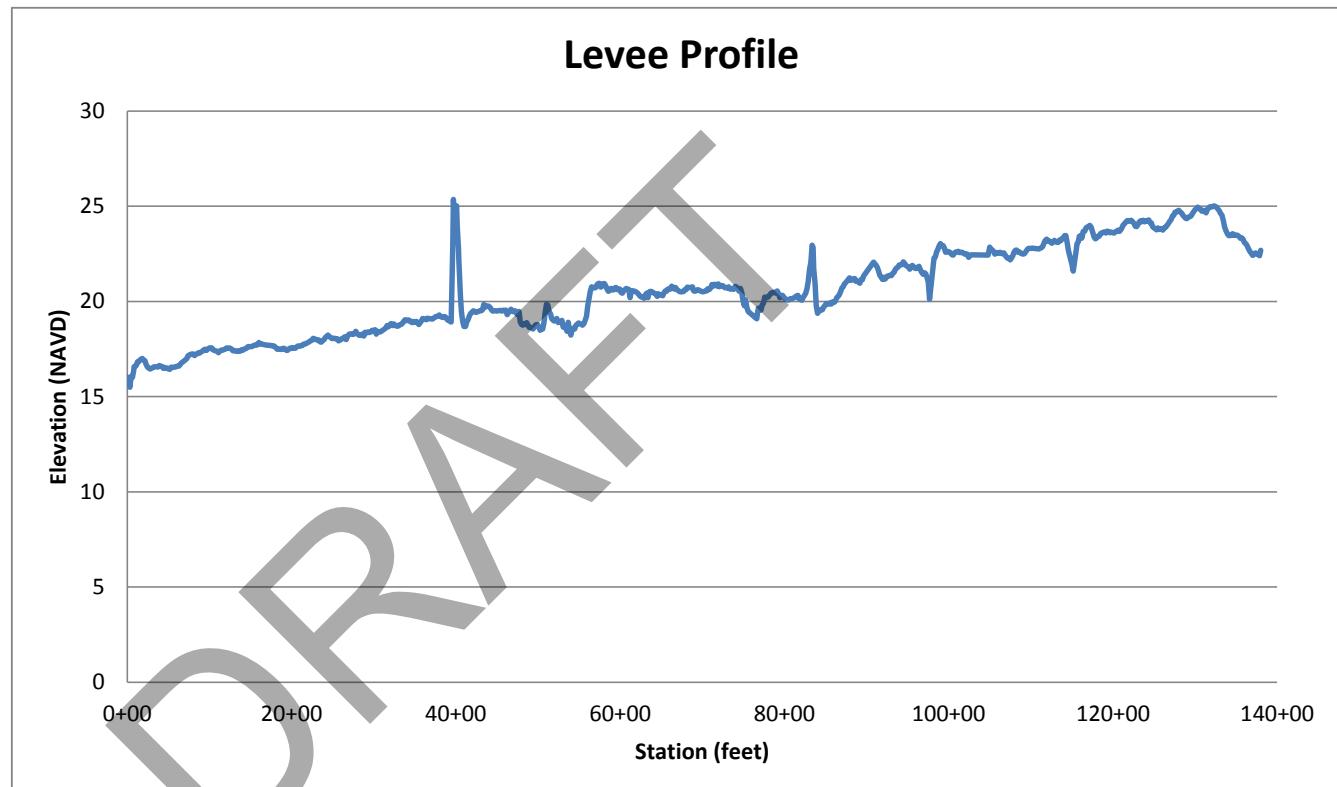


## *Puyallup Authorized Levee Right Bank*

*Puyallup River*

<b>Min</b>	15.49
<b>Max</b>	25.36

<b>Station Begin</b>	0+00
<b>Station End</b>	138+03

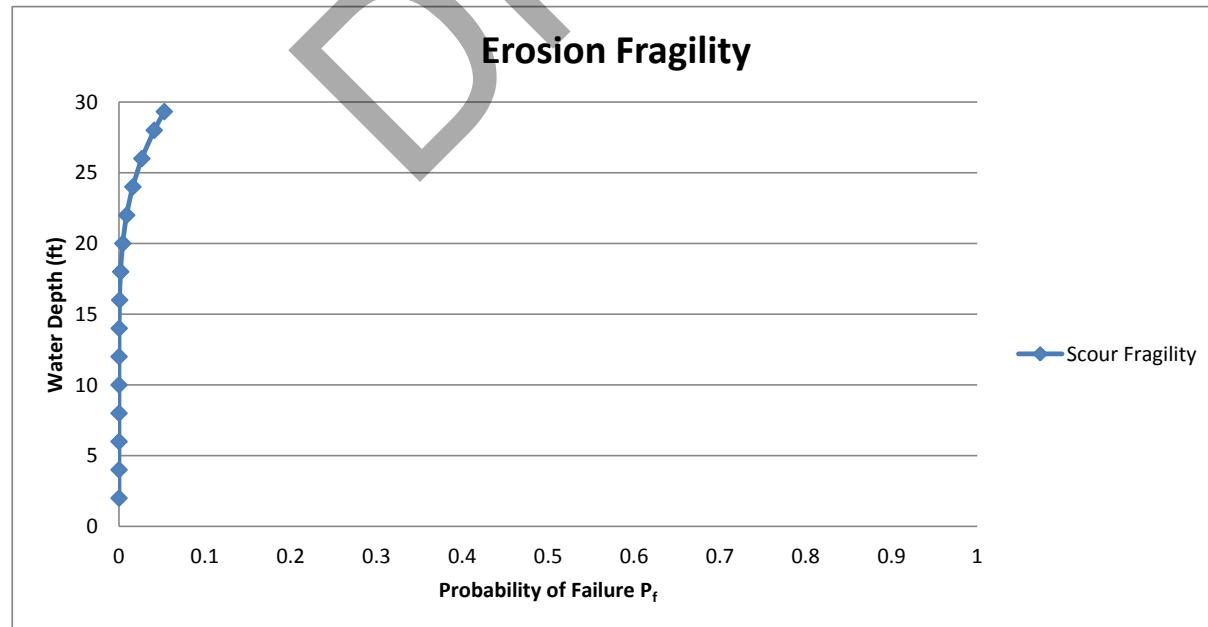


## Surface Erosion Analysis

### Puyallup Authorized Right Bank Levee

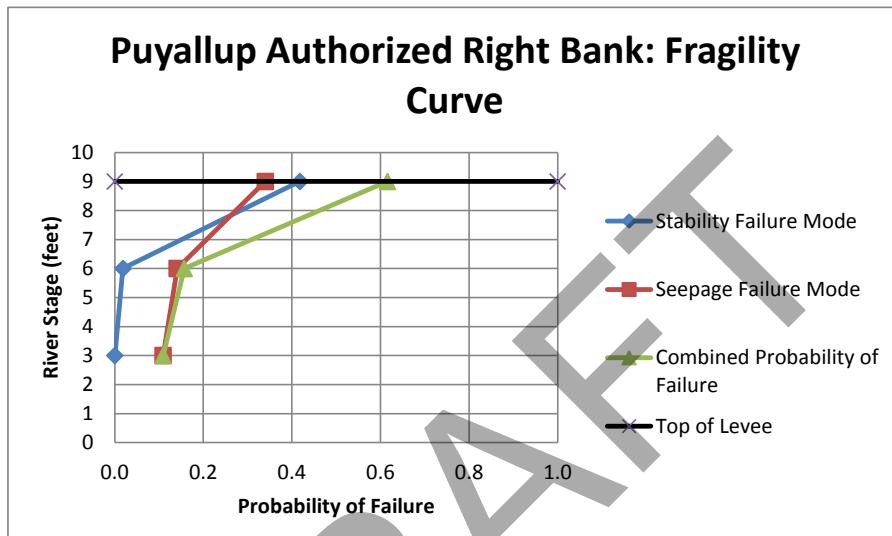
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.00034	CV(s) =	0.1	0.000034
Manning's "n"	n =	0.035	CV(n) =	0.15	0.00525
Scouring Velocity		Vcrit = 11.25	CV(vcrit)		2.24940526

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	1.243	0.1581139		-2.202792949	0.254950976	-8.64006	2.8091E-18
4	1.973	0.1581139		-1.740694829	0.254950976	-6.82757	4.3183E-12
6	2.585	0.1581139		-1.470384757	0.254950976	-5.76732	4.027E-09
8	3.131	0.1581139		-1.278596709	0.254950976	-5.01507	2.6507E-07
10	3.634	0.1581139		-1.129834341	0.254950976	-4.43157	4.6774E-06
12	4.103	0.1581139		-1.008286636	0.254950976	-3.95483	3.8295E-05
14	4.548	0.1581139		-0.905519517	0.254950976	-3.55174	0.00019135
16	4.971	0.1581139		-0.816498588	0.254950976	-3.20257	0.00068103
18	5.377	0.1581139		-0.737976564	0.254950976	-2.89458	0.00189832
20	5.768	0.1581139		-0.667736221	0.254950976	-2.61908	0.0044084
22	6.147	0.1581139		-0.604196101	0.254950976	-2.36985	0.0088976
24	6.514	0.1581139		-0.546188516	0.254950976	-2.14233	0.01608356
26	6.871	0.1581139		-0.492826711	0.254950976	-1.93303	0.02661653
28	7.219	0.1581139		-0.443421396	0.254950976	-1.73924	0.04099612
29.32	7.444	0.1581139		-0.412711152	0.254950976	-1.61879	0.05274662



Puyallup Authorized Right Bank Levee					
Fragility Curve					
Cross Section from STA 85+04					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 9' +					
9	0.418	9	0.340	9	0.616
6	0.019	6	0.141	6	0.157
3	2.3E-08	3	0.109	3	0.109



OVERTOPPING - 9' +	
Top of Levee	
9	0
9	1

Soil Unit	Stability	TOL		TOL - 3'		TOL - 6'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	1.17	0.58	1.50	0.41	1.86	0.23	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.17	0.58	1.49	0.41	1.86	0.23	γB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.07	0.58	1.40	0.41	1.74	0.23	γB +1SD
	log(K <sub>h</sub> )-1SD	1.19	0.58	1.54	0.41	1.89	0.23	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	1.17	0.58	1.50	0.41	1.87	0.24	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	γ -1SD	1.14	0.46	1.49	0.35	1.87	0.21	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	γ +1SD	1.19	0.59	1.51	0.45	1.85	0.26	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	φ -1SD	1.12	0.67	1.42	0.47	1.77	0.23	log(K <sub>h</sub> )-1SD
2	φ +1SD	1.22	0.53	1.58	0.40	1.96	0.23	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.23	0.82	1.54	0.59	1.88	0.33	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.12	0.32	1.57	0.23	1.85	0.09	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	0.53	(i)	1.26	(i)	1.78	(i)	
	log(K <sub>h</sub> )+1SD	1.43		1.74		2.01		
	γ -1SD	1.12		1.45		1.81		
	γ +1SD	1.22		1.55		1.92		
	γ -1SD	1.09		1.40		1.75		
	γ +1SD	1.25		1.60		1.98		

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Puyallup Authorized Right Bank Levee
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Puyallup Authorized Right Bank Levee cross section from STA 85+04. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	52.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-4	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-5	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	52.6	1.5	1.5	-4	-5	0	0	0	0	0	1.45	
2	47.6	1.5	1.5	-4	-5	0	0	0	0	0	1.32	
3	57.6	1.5	1.5	-4	-5	0	0	0	0	0	1.59	0.28
4	52.6	1	1.5	-4	-5	0	0	0	0	0	1.45	
5	52.6	2	1.5	-4	-5	0	0	0	0	0	1.45	0
6	52.6	1.5	1	-4	-5	0	0	0	0	0	1.83	
7	52.6	1.5	2	-4	-5	0	0	0	0	0	1.43	-0.40377
8	52.6	1.5	1.5	-5	-5	0	0	0	0	0	1.26	
9	52.6	1.5	1.5	-3	-5	0	0	0	0	0	1.59	0.32744
10	52.6	1.5	1.5	-4	-6	0	0	0	0	0	1.03	
11	52.6	1.5	1.5	-4	-4	0	0	0	0	0	2.63	1.60623
12	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
13	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
14	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
15	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
16	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
17	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
18	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
19	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
20	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
21	52.6	1.5	1.5	-4	-5	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	0.855
Coefficient of variation of F,	$V_F$	0.589
Log normal reliability index,	$\beta_{LN}$	0.413
Reliability		0.660
Probability of failure		0.340

**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

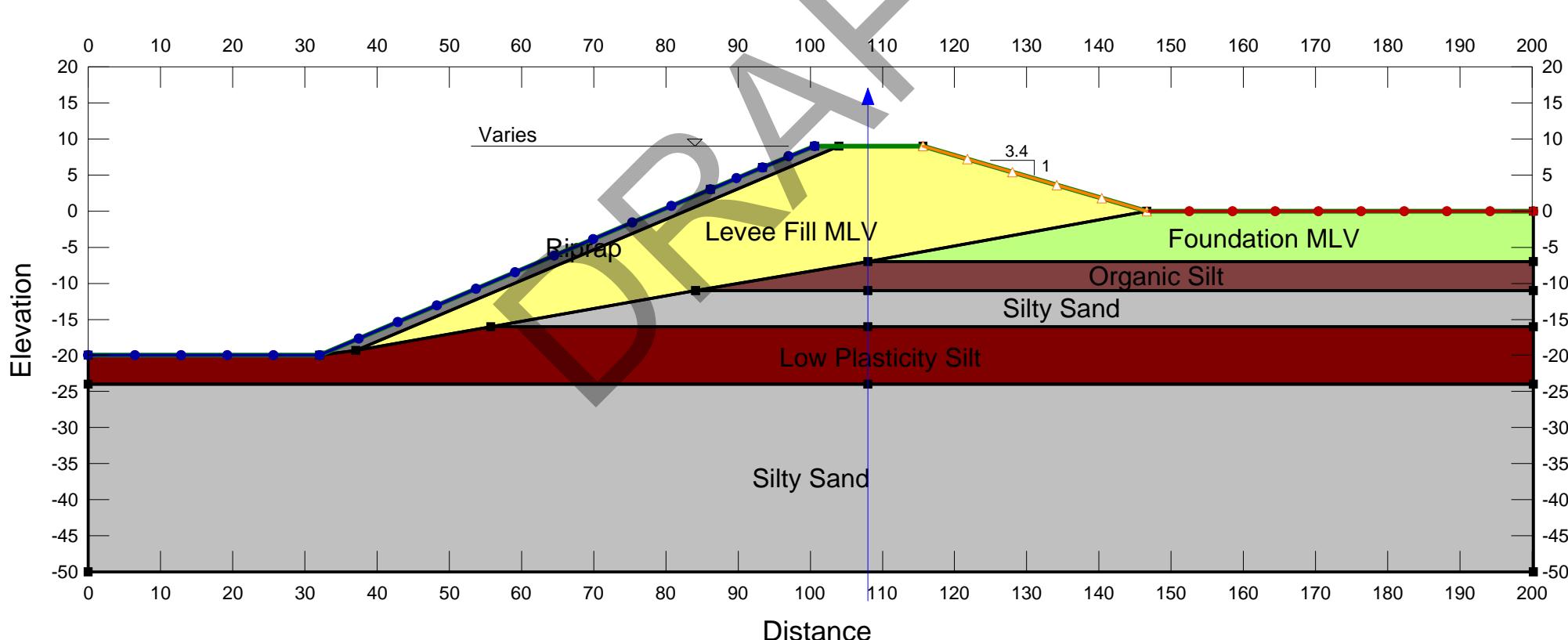
**Organic Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (ML)**  
 log(K-Sat): -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 log(K-Sat): -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

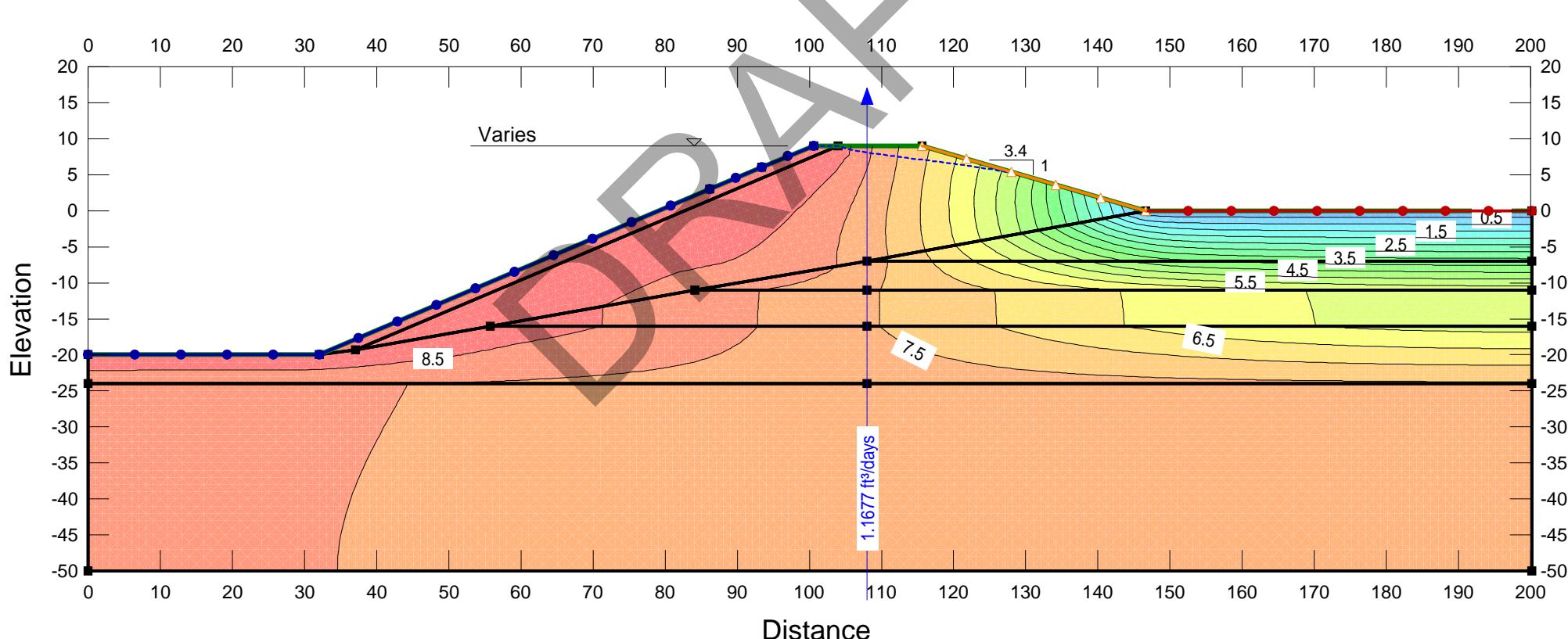
**Organic Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (ML)**  
 log(K-Sat): -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 log(K-Sat): -3 cm/s  
 KH/KV Ratio: 1.5  
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**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

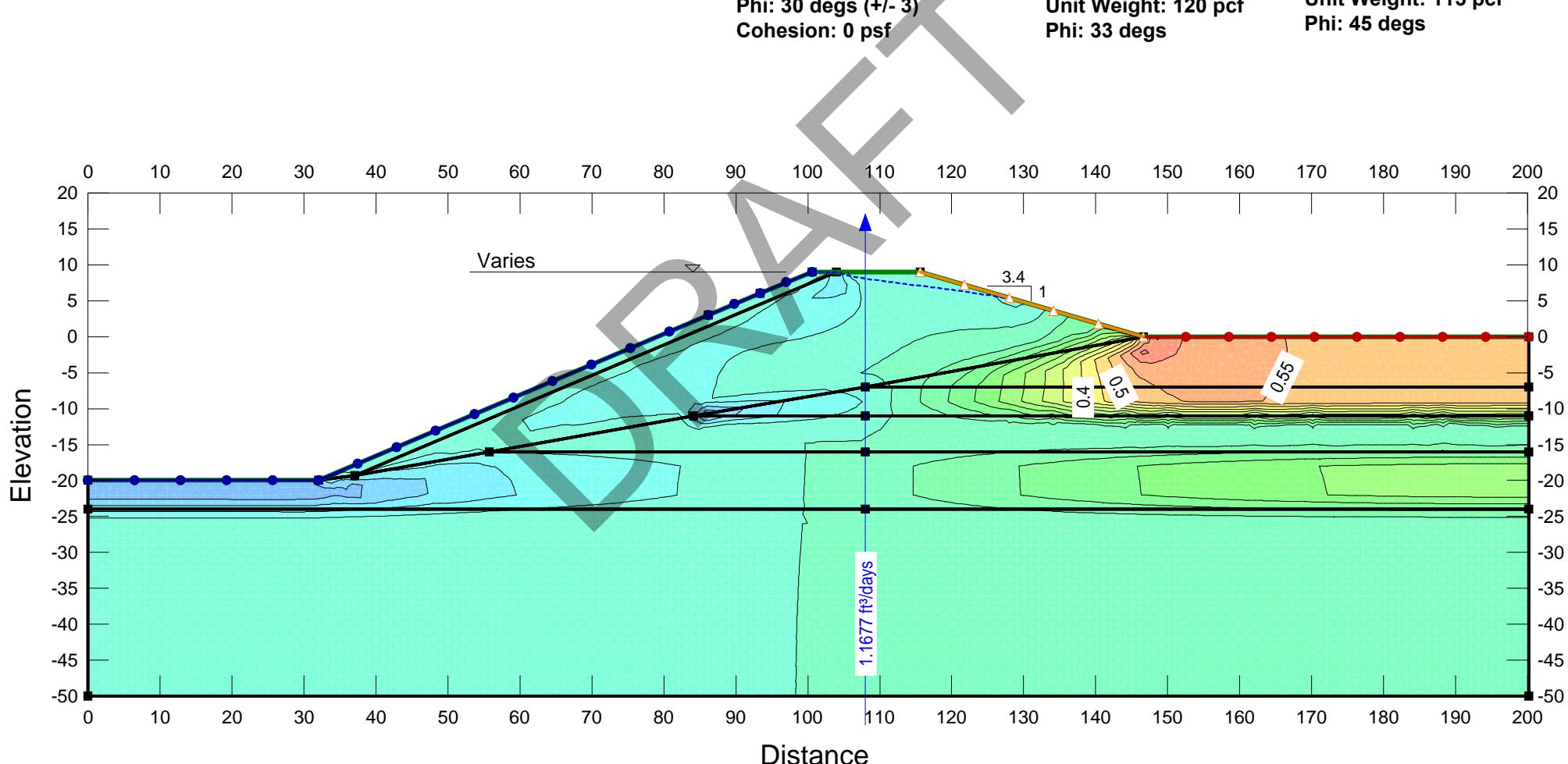
**Levee Foundation (ML)**  
 log(K-Sat): -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Organic Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
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 Cohesion: 100 psf

**Silty Sand**  
 log(K-Sat): -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
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**Low Plasticity Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Taylor's series method spreadsheet**

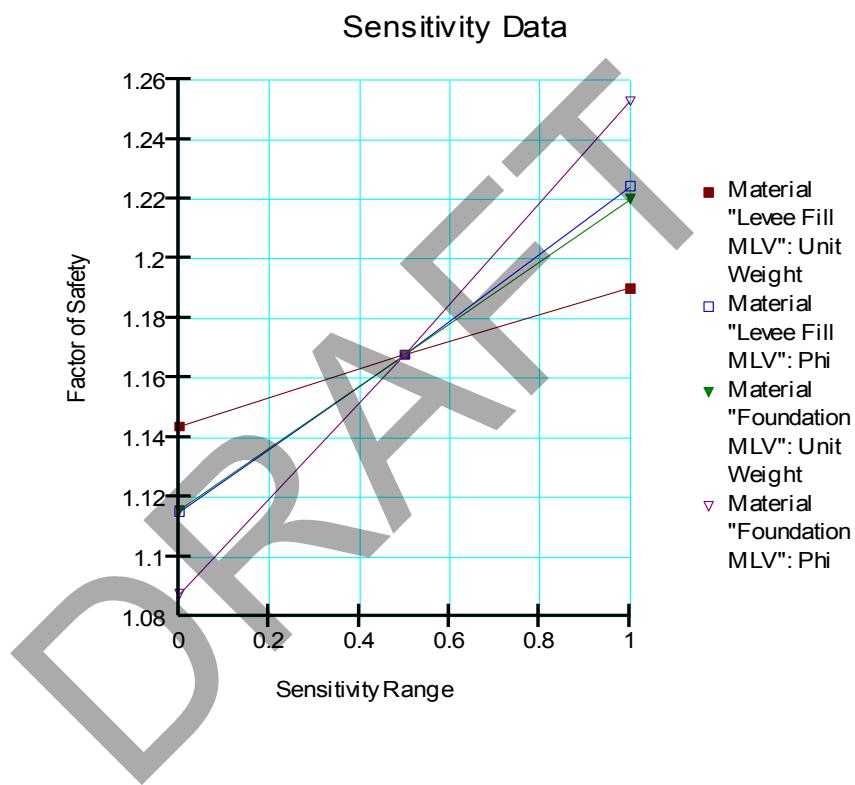
Project	Puyallup General Investigation
Feature	Puyallup Authorized Right Bank Levee
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Puyallup Authorized Right Bank Levee cross section from STA 85+04. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-4	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	34	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-5	cm/s	1
7	$\gamma_{sat}$ (Foundation)	115	pcf	5
8	$\phi'$ (Foundation)	30	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-4	125	34	1.5	-5	115	30	0	0	1.17	
2	1	-4	125	34	1.5	-5	115	30	0	0	1.17	
3	2	-4	125	34	1.5	-5	115	30	0	0	1.07	-0.1
4	1.5	-5	125	34	1.5	-5	115	30	0	0	1.19	
5	1.5	-3	125	34	1.5	-5	115	30	0	0	1.17	-0.02
6	1.5	-4	120	34	1.5	-5	115	30	0	0	1.14	
7	1.5	-4	130	34	1.5	-5	115	30	0	0	1.19	0.04622
8	1.5	-4	125	31	1.5	-5	115	30	0	0	1.12	
9	1.5	-4	125	37	1.5	-5	115	30	0	0	1.22	0.10908
10	1.5	-4	125	34	1	-5	115	30	0	0	1.23	
11	1.5	-4	125	34	2	-5	115	30	0	0	1.12	-0.11
12	1.5	-4	125	34	1.5	-6	115	30	0	0	0.53	
13	1.5	-4	125	34	1.5	-4	115	30	0	0	1.43	0.9
14	1.5	-4	125	34	1.5	-5	110	30	0	0	1.12	
15	1.5	-4	125	34	1.5	-5	120	30	0	0	1.22	0.10446
16	1.5	-4	125	34	1.5	-5	115	27	0	0	1.09	
17	1.5	-4	125	34	1.5	-5	115	33	0	0	1.25	0.16541
18	1.5	-4	125	34	1.5	-5	115	30	0	0		
19	1.5	-4	125	34	1.5	-5	115	30	0	0		0
20	1.5	-4	125	34	1.5	-5	115	30	0	0		
21	1.5	-4	125	34	1.5	-5	115	30	0	0		0

Standard deviation of F,	$\sigma_F$	0.470
Coefficient of variation of F,	$V_F$	0.403
Log normal reliability index,	$\beta_{LN}$	0.207
Reliability		0.582
Probability of failure		0.418

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.1438736	1.1152628	1.1156983	1.0876241
0.5	1.1679897	1.1679897	1.1679897	1.1679897
1	1.1900977	1.2243447	1.2201578	1.2530305



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

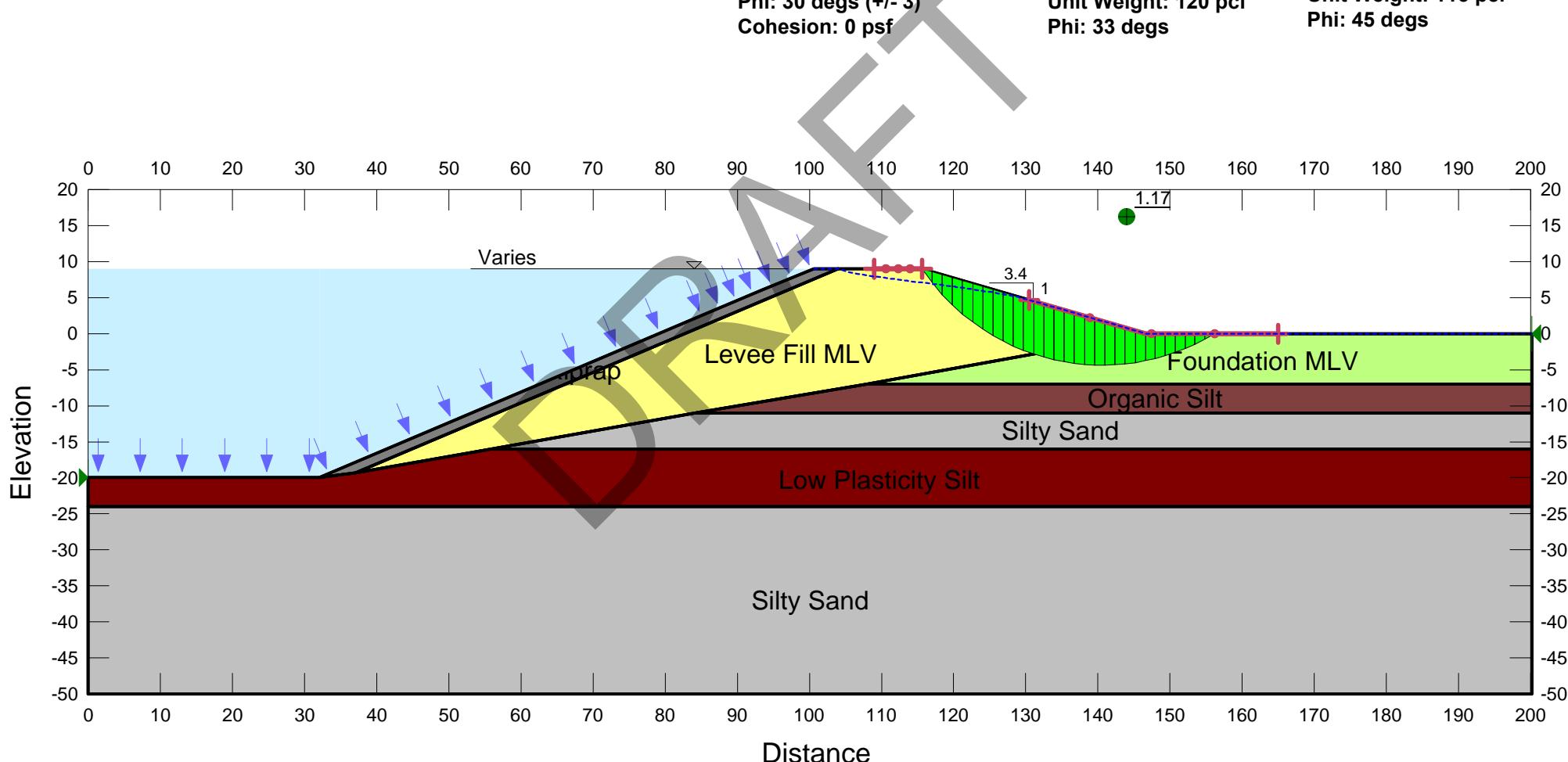
**Levee Foundation (ML)**  
 $\log(K\text{-Sat})$ : -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Organic Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Puyallup Authorized Right Bank Levee
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Puyallup Authorized Right Bank Levee cross section from STA 85+04. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	52.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-4	cm/s	1
5	$\log(K_h)$ (Foundation)	-5	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	52.6	1.5	1.5	-4	-5	0	0	0	0	0	2.06	
2	47.6	1.5	1.5	-4	-5	0	0	0	0	0	1.86	
3	57.6	1.5	1.5	-4	-5	0	0	0	0	0	2.25	0.39087
4	52.6	1	1.5	-4	-5	0	0	0	0	0	2.06	
5	52.6	2	1.5	-4	-5	0	0	0	0	0	2.06	0
6	52.6	1.5	1	-4	-5	0	0	0	0	0	2.40	
7	52.6	1.5	2	-4	-5	0	0	0	0	0	1.87	-0.52834
8	52.6	1.5	1.5	-5	-5	0	0	0	0	0	1.79	
9	52.6	1.5	1.5	-3	-5	0	0	0	0	0	2.12	0.32674
10	52.6	1.5	1.5	-4	-6	0	0	0	0	0	1.43	
11	52.6	1.5	1.5	-4	-4	0	0	0	0	0	3.69	2.25629
12	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
13	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
14	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
15	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
16	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
17	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
18	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
19	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
20	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
21	52.6	1.5	1.5	-4	-5	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	1.186
Coefficient of variation of F,	$V_F$	0.577
Log normal reliability index,	$\beta_{LN}$	1.076
Reliability		0.859
Probability of failure		0.141

**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

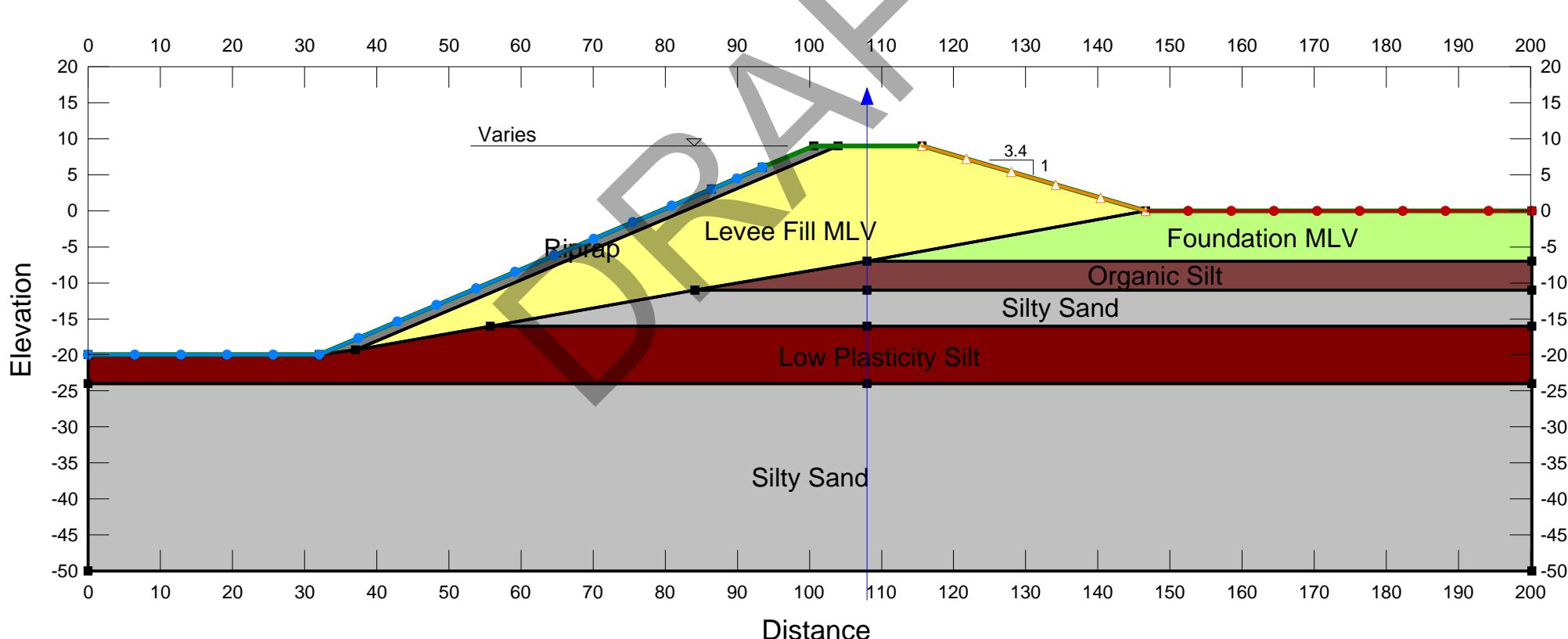
**Organic Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (ML)**  
 $\log(K\text{-Sat})$ : -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
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 Unit Weight: 125 pcf (+/- 5)  
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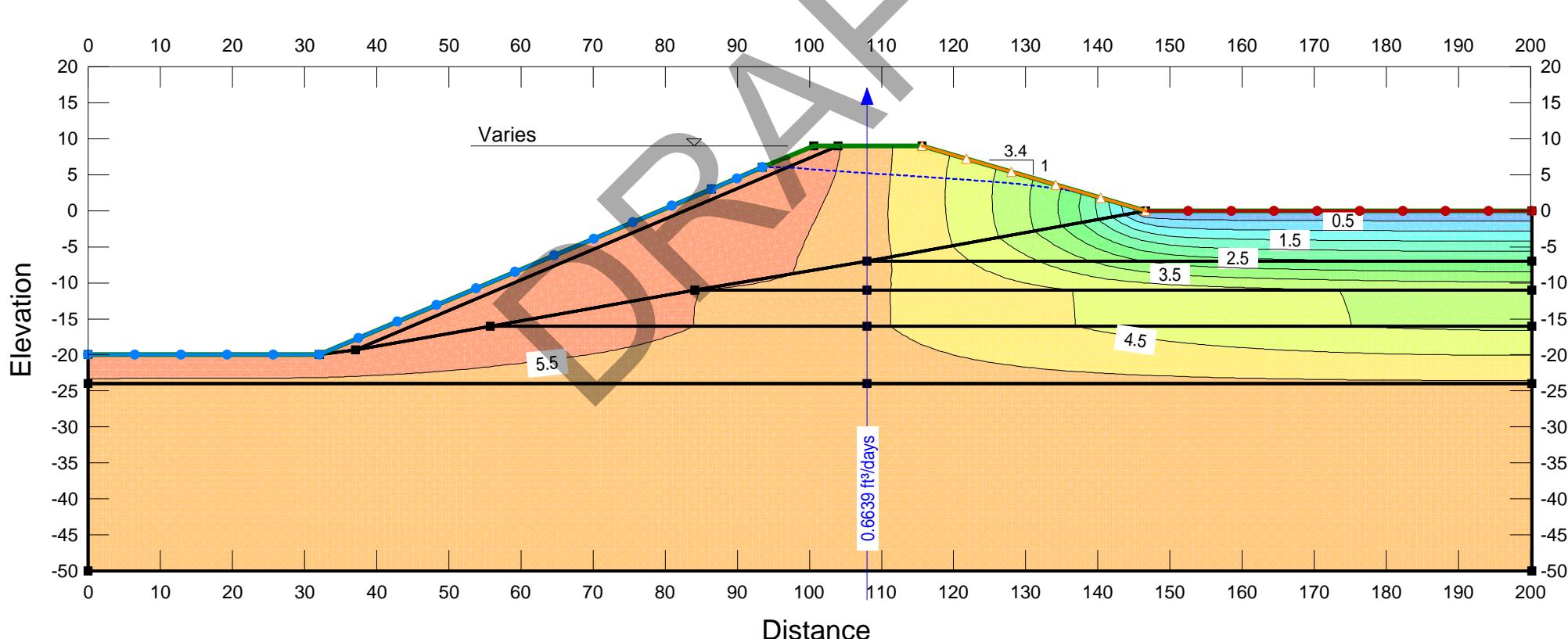
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 Unit Weight: 115 pcf  
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 Cohesion: 0 psf

**Levee Foundation (ML)**  
 log(K-Sat): -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 log(K-Sat): -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

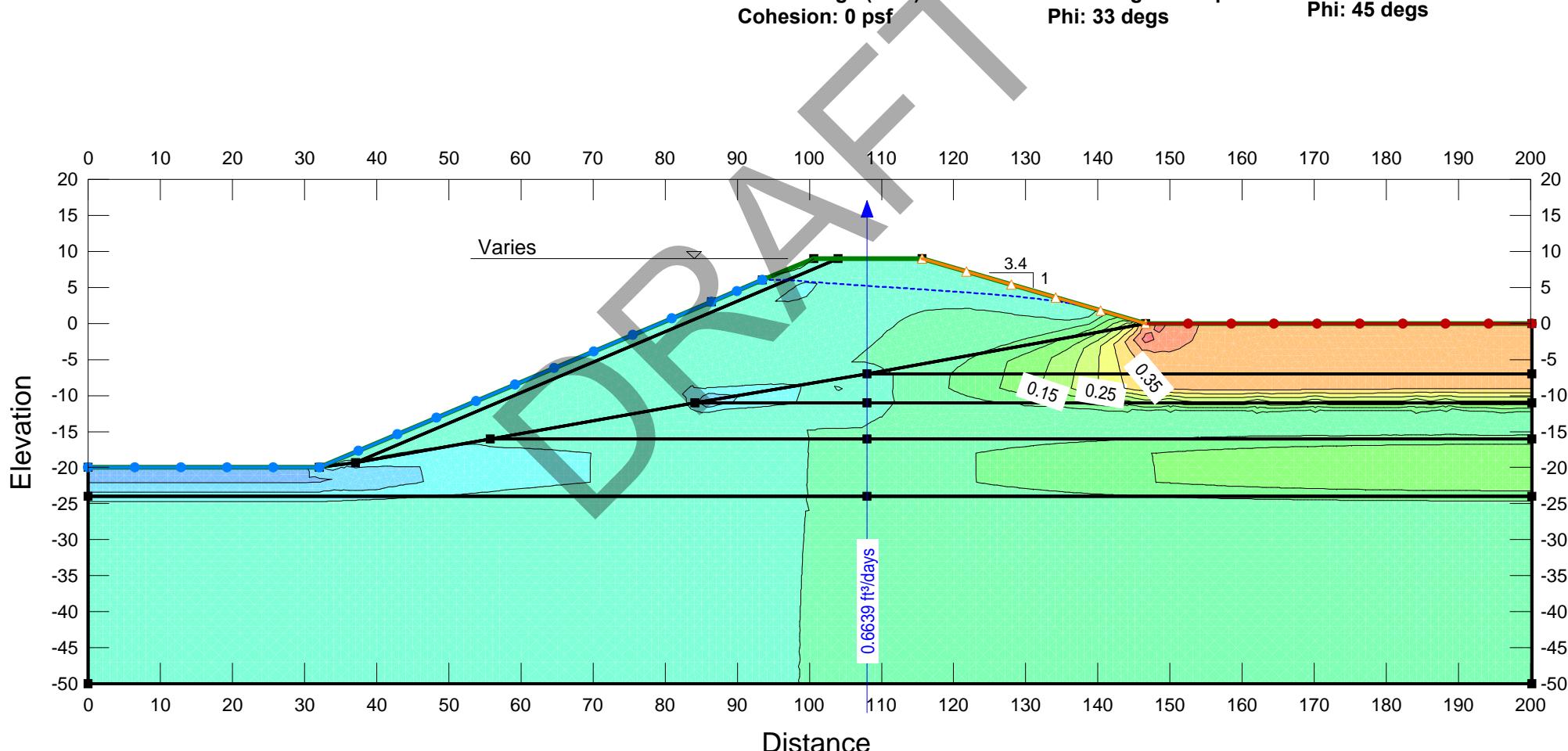
**Organic Silt**  
 log(K-Sat): -5 cm/s  
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**Levee Foundation (ML)**  
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**Silty Sand**  
 log(K-Sat): -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



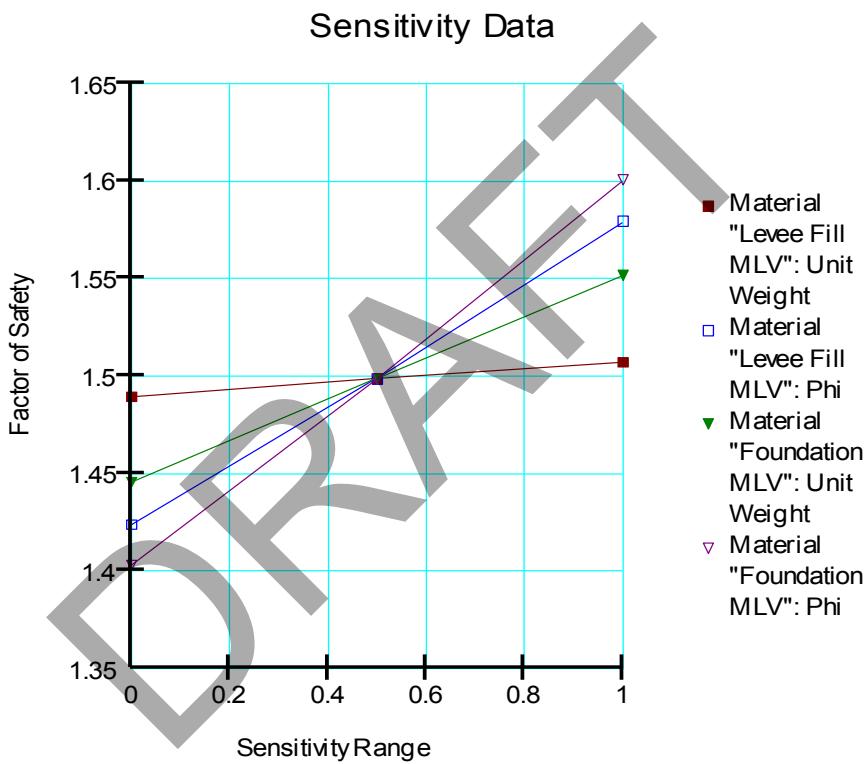
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Puyallup Authorized Right Bank Levee
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Puyallup Authorized Right Bank Levee cross section from STA 85+04. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-4	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	34	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-5	cm/s	1
7	$\gamma_{sat}$ (Foundation)	115	pcf	5
8	$\phi'$ (Foundation)	30	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-4	125	34	1.5	-5	115	30	0	0	1.50	
2	1	-4	125	34	1.5	-5	115	30	0	0	1.49	
3	2	-4	125	34	1.5	-5	115	30	0	0	1.40	-0.09
4	1.5	-5	125	34	1.5	-5	115	30	0	0	1.54	
5	1.5	-3	125	34	1.5	-5	115	30	0	0	1.50	-0.04
6	1.5	-4	120	34	1.5	-5	115	30	0	0	1.49	
7	1.5	-4	130	34	1.5	-5	115	30	0	0	1.51	0.01746
8	1.5	-4	125	31	1.5	-5	115	30	0	0	1.42	
9	1.5	-4	125	37	1.5	-5	115	30	0	0	1.58	0.15541
10	1.5	-4	125	34	1	-5	115	30	0	0	1.54	
11	1.5	-4	125	34	2	-5	115	30	0	0	1.57	0.03
12	1.5	-4	125	34	1.5	-6	115	30	0	0	1.26	
13	1.5	-4	125	34	1.5	-4	115	30	0	0	1.74	0.48
14	1.5	-4	125	34	1.5	-5	110	30	0	0	1.45	
15	1.5	-4	125	34	1.5	-5	120	30	0	0	1.55	0.10574
16	1.5	-4	125	34	1.5	-5	115	27	0	0	1.40	
17	1.5	-4	125	34	1.5	-5	115	33	0	0	1.60	0.19753
18	1.5	-4	125	34	1.5	-5	115	30	0	0		
19	1.5	-4	125	34	1.5	-5	115	30	0	0		0
20	1.5	-4	125	34	1.5	-5	115	30	0	0		
21	1.5	-4	125	34	1.5	-5	115	30	0	0		0

Standard deviation of F,	$\sigma_F$	0.281
Coefficient of variation of F,	$V_F$	0.187
Log normal reliability index,	$\beta_{LN}$	2.084
Reliability		0.981
Probability of failure		0.019

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.4895158	1.4239234	1.4458559	1.4031103
0.5	1.4986435	1.4986435	1.4986435	1.4986435
1	1.5069733	1.5793365	1.5515957	1.6006355



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill (SM)**  
 $\log(K\text{-Sat})$ : -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

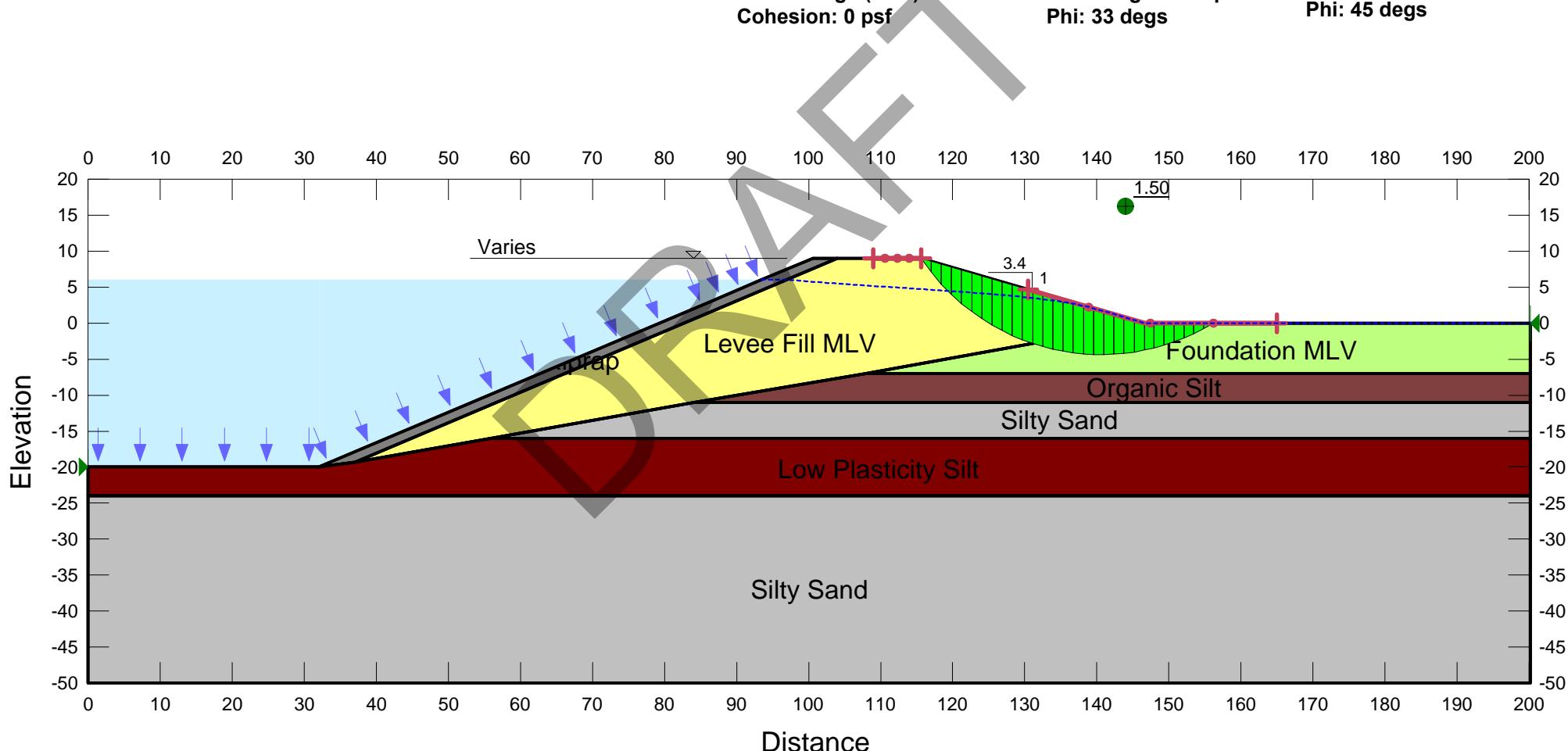
**Organic Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation (ML)**  
 $\log(K\text{-Sat})$ : -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Puyallup Authorized Right Bank Levee
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Puyallup Authorized Right Bank Levee cross section from STA 85+04. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	52.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-4	cm/s	1
5	$\log(K_h)$ (Foundation)	-5	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	52.6	1.5	1.5	-4	-5	0	0	0	0	0	3.66	
2	47.6	1.5	1.5	-4	-5	0	0	0	0	0	3.32	
3	57.6	1.5	1.5	-4	-5	0	0	0	0	0	4.01	0.69677
4	52.6	1	1.5	-4	-5	0	0	0	0	0	3.60	
5	52.6	2	1.5	-4	-5	0	0	0	0	0	3.51	-0.09006
6	52.6	1.5	1	-4	-5	0	0	0	0	0	4.11	
7	52.6	1.5	2	-4	-5	0	0	0	0	0	3.24	-0.86983
8	52.6	1.5	1.5	-5	-5	0	0	0	0	0	3.64	
9	52.6	1.5	1.5	-3	-5	0	0	0	0	0	3.66	0.02375
10	52.6	1.5	1.5	-4	-6	0	0	0	0	0	2.55	
11	52.6	1.5	1.5	-4	-4	0	0	0	0	0	9.37	6.81171
12	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
13	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
14	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
15	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
16	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
17	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
18	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
19	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
20	52.6	1.5	1.5	-4	-5	0	0	0	0	0		
21	52.6	1.5	1.5	-4	-5	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	3.451
Coefficient of variation of F,	$V_F$	0.942
Log normal reliability index,	$\beta_{LN}$	1.232
Reliability		0.891
Probability of failure		0.109

**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill**  
 $\log(K\text{-Sat})$ : -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

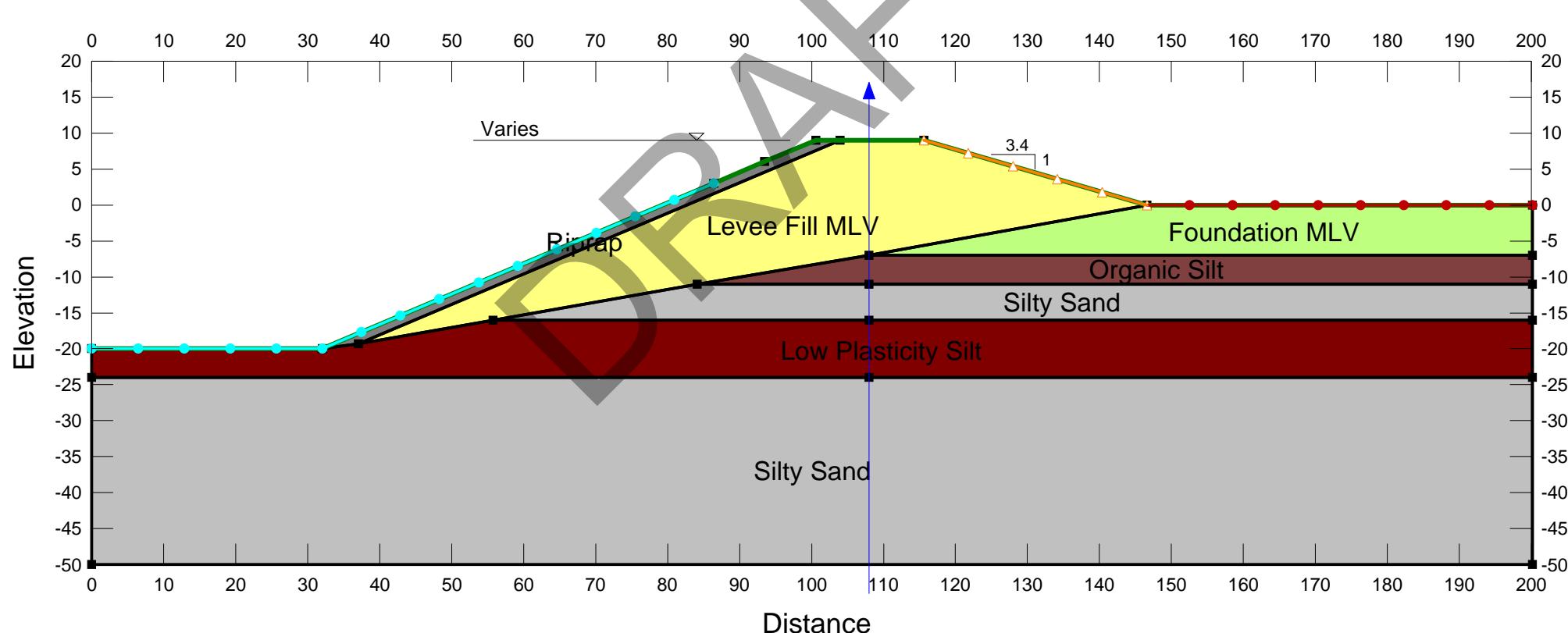
**Organic Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation**  
 $\log(K\text{-Sat})$ : -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill**  
 $\log(K\text{-Sat})$ : -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

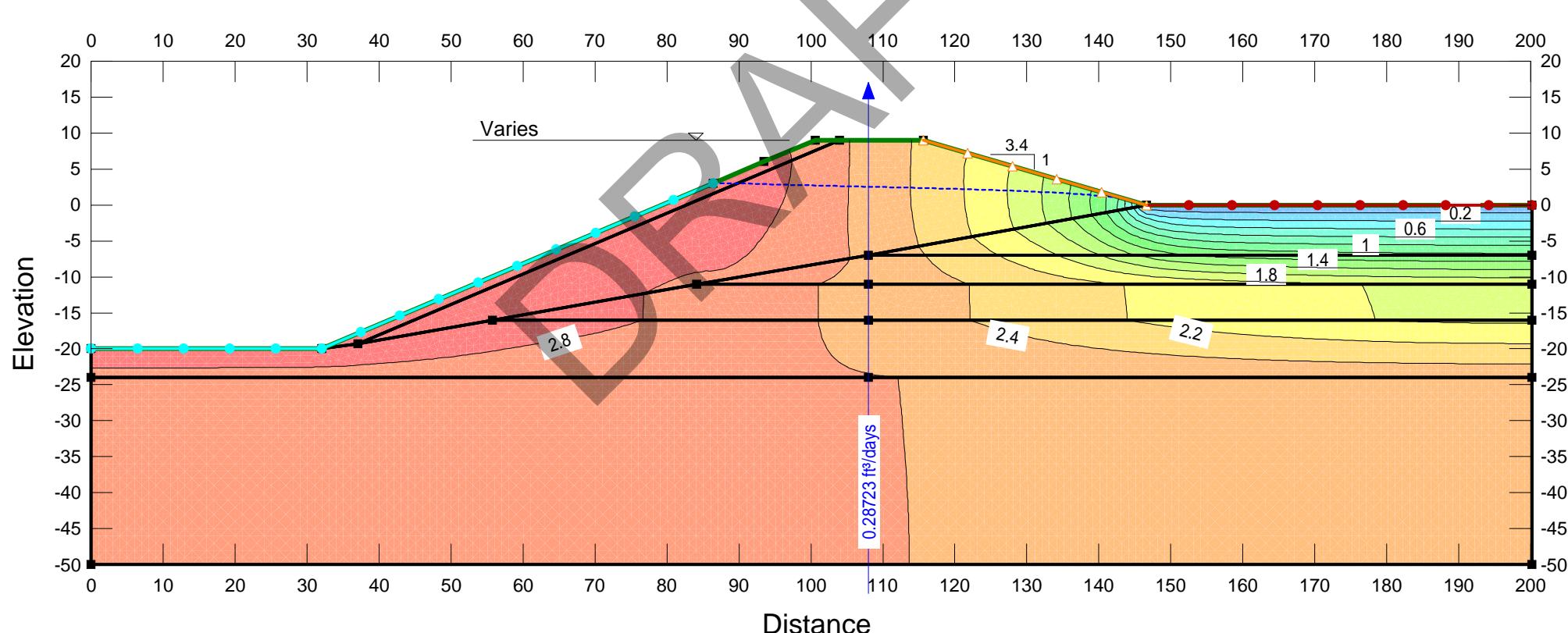
**Organic Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
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**Levee Foundation**  
 $\log(K\text{-Sat})$ : -5 cm/s (+/- 1)  
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 Cohesion: 0 psf

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

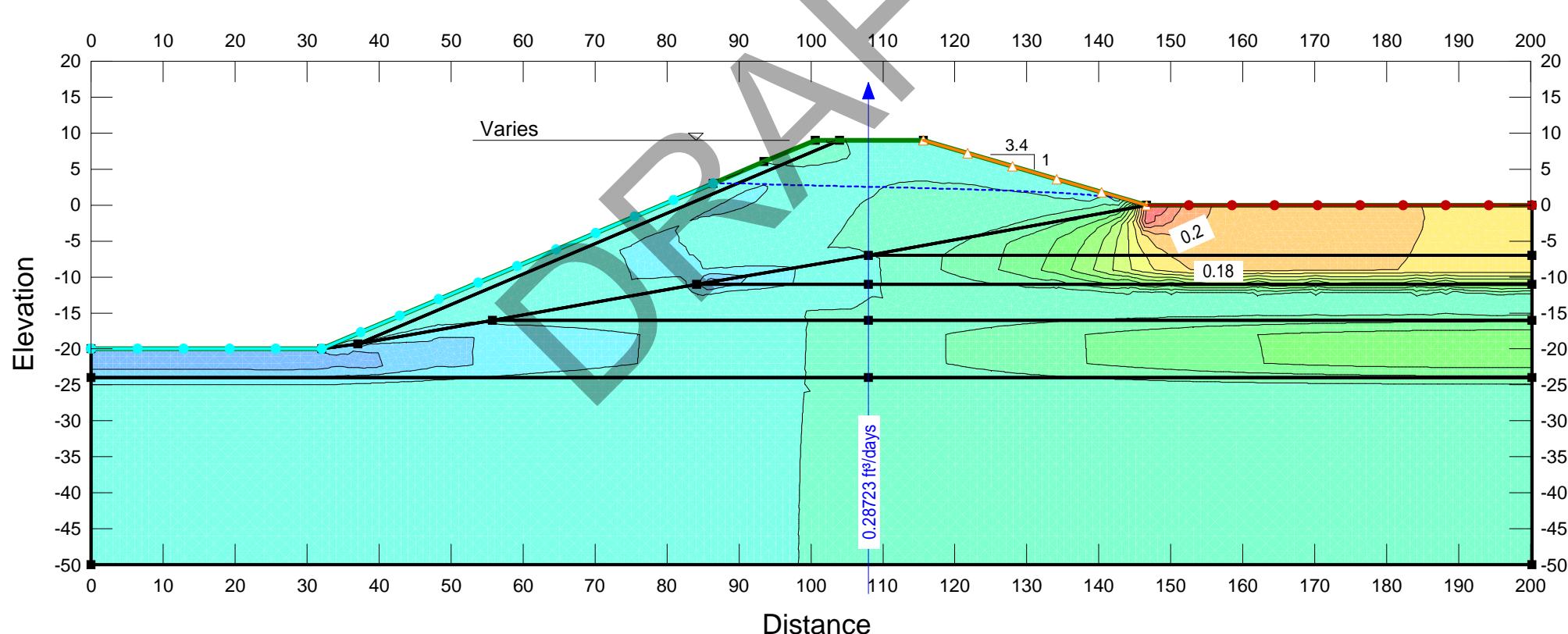
**Organic Silt**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 log(K-Sat): -5 cm/s  
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**Levee Foundation**  
 log(K-Sat): -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
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**Silty Sand**  
 log(K-Sat): -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



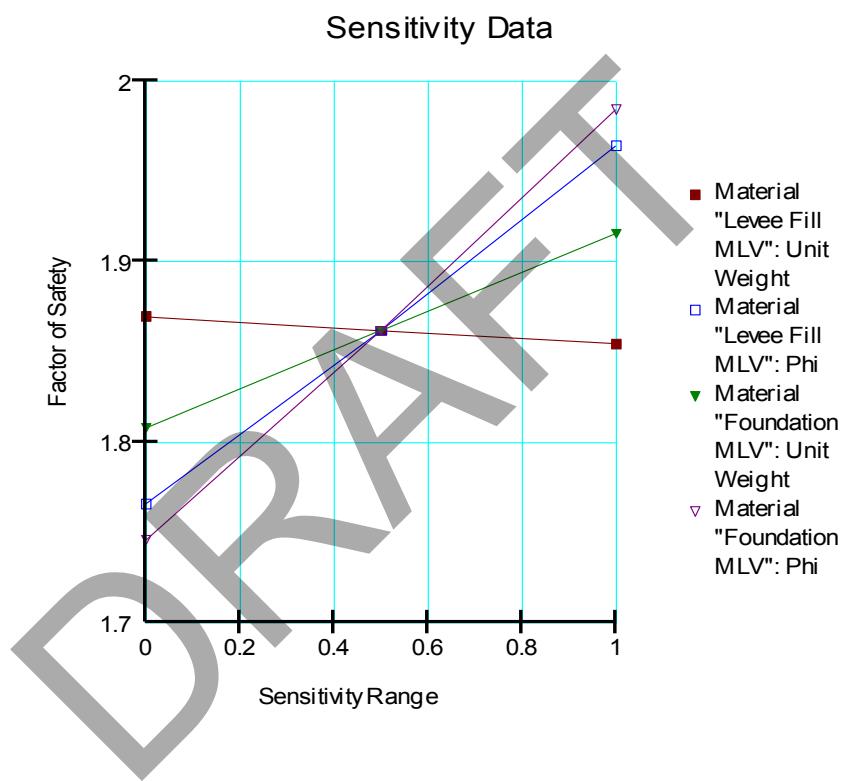
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Puyallup Authorized Right Bank Levee
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Puyallup Authorized Right Bank Levee cross section from STA 85+04. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-4	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	34	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-5	cm/s	1
7	$\gamma_{sat}$ (Foundation)	115	pcf	5
8	$\phi'$ (Foundation)	30	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-4	125	34	1.5	-5	115	30	0	0	1.86	
2	1	-4	125	34	1.5	-5	115	30	0	0	1.86	
3	2	-4	125	34	1.5	-5	115	30	0	0	1.74	-0.12
4	1.5	-5	125	34	1.5	-5	115	30	0	0	1.89	
5	1.5	-3	125	34	1.5	-5	115	30	0	0	1.87	-0.02
6	1.5	-4	120	34	1.5	-5	115	30	0	0	1.87	
7	1.5	-4	130	34	1.5	-5	115	30	0	0	1.85	-0.01519
8	1.5	-4	125	31	1.5	-5	115	30	0	0	1.77	
9	1.5	-4	125	37	1.5	-5	115	30	0	0	1.96	0.19854
10	1.5	-4	125	34	1	-5	115	30	0	0	1.88	
11	1.5	-4	125	34	2	-5	115	30	0	0	1.85	-0.03
12	1.5	-4	125	34	1.5	-6	115	30	0	0	1.78	
13	1.5	-4	125	34	1.5	-4	115	30	0	0	2.01	0.23
14	1.5	-4	125	34	1.5	-5	110	30	0	0	1.81	
15	1.5	-4	125	34	1.5	-5	120	30	0	0	1.92	0.10746
16	1.5	-4	125	34	1.5	-5	115	27	0	0	1.75	
17	1.5	-4	125	34	1.5	-5	115	33	0	0	1.98	0.23841
18	1.5	-4	125	34	1.5	-5	115	30	0	0		
19	1.5	-4	125	34	1.5	-5	115	30	0	0		0
20	1.5	-4	125	34	1.5	-5	115	30	0	0		
21	1.5	-4	125	34	1.5	-5	115	30	0	0		0

Standard deviation of F,	$\sigma_F$	0.210
Coefficient of variation of F,	$V_F$	0.113
Log normal reliability index,	$\beta_{LN}$	5.468
Reliability		1.000
Probability of failure		2.3E-08

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.8696934	1.765902	1.8082076	1.7460334
0.5	1.8617585	1.8617585	1.8617585	1.8617585
1	1.8545012	1.9644376	1.9156717	1.9844419



**Puyallup Authorized Right Bank Levee**  
**Puyallup River**  
**STA 85+04**

**Levee Fill**  
 $\log(K\text{-Sat})$ : -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

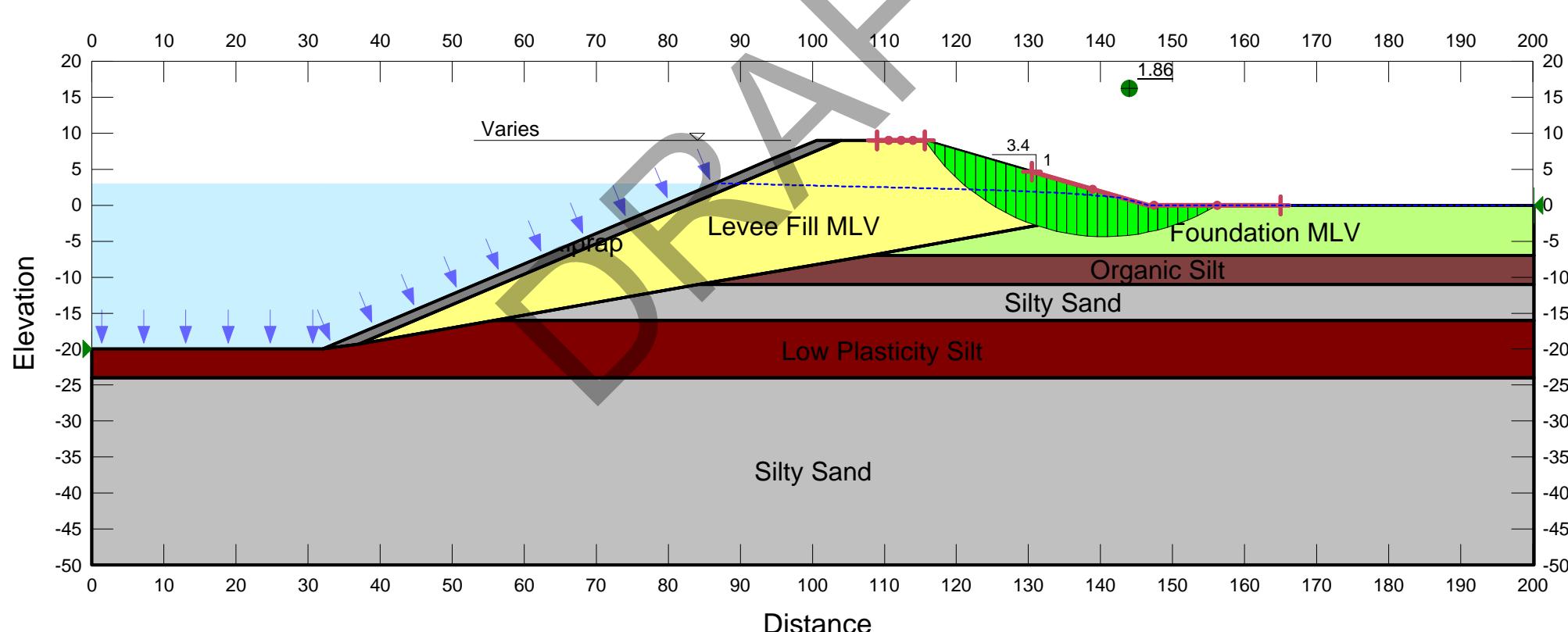
**Organic Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 100 pcf  
 Phi: 27 degs  
 Cohesion: 100 psf

**Low Plasticity Silt**  
 $\log(K\text{-Sat})$ : -5 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 30 degs  
 Cohesion: 0 psf

**Levee Foundation**  
 $\log(K\text{-Sat})$ : -5 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 115 pcf (+/- 5)  
 Phi: 30 degs (+/- 3)  
 Cohesion: 0 psf

**Silty Sand**  
 $\log(K\text{-Sat})$ : -3 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 33 degs

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.0  
 Unit Weight: 115 pcf  
 Phi: 45 degs



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Riddell Cross Section Model & Erosion Analysis

#### General Information

Location:	Pierce County, Washington
River:	Carbon River
Levee Segment Name:	Riddell
Station:	18+00

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Vegetation maintenance issues and minor toe scour damage were noted.

#### Levee Geometry

Crown Width (W)	12 Feet
Landward Levee Height (H)	8 Feet
Riverward Slope (R)	1.5 H:1V
Landward Slope (L)	2 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	8 Feet
Breach Width at Top of Levee	179 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.56 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is a medium dense poorly graded SAND with gravel (SP).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )	
	Loose / Soft		Low
X	Medium	X	Medium
	Dense / Stiff		High

**Remarks:** Levee embankment material is a medium dense silty SAND with gravel (SM).

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
133.32	1.00
133.32	0.31
130.32	0.15
127.32	0.06
125.32	0.02

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

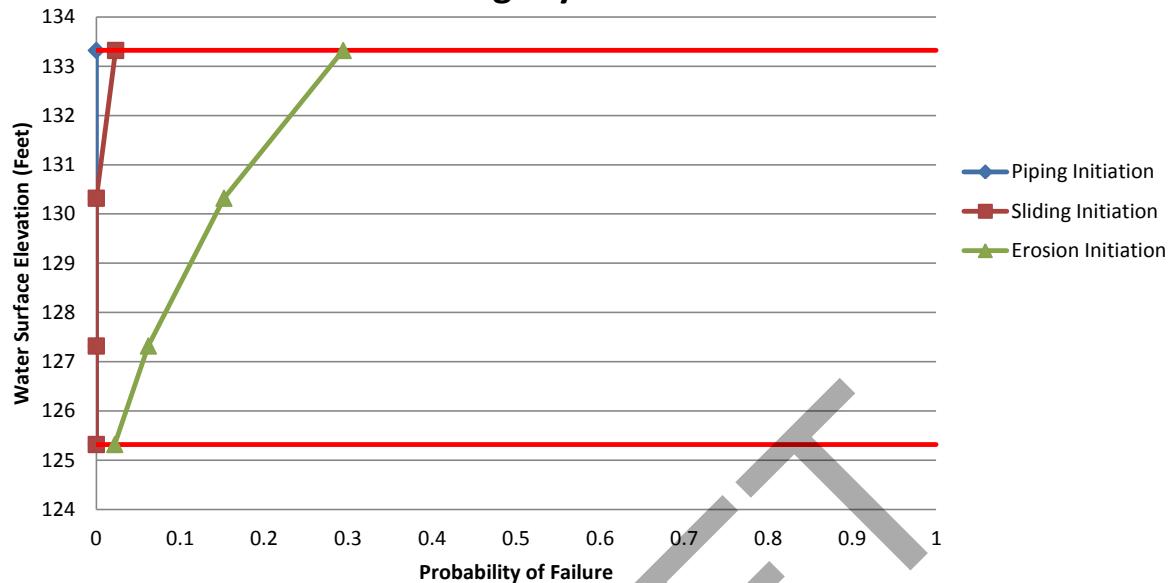
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

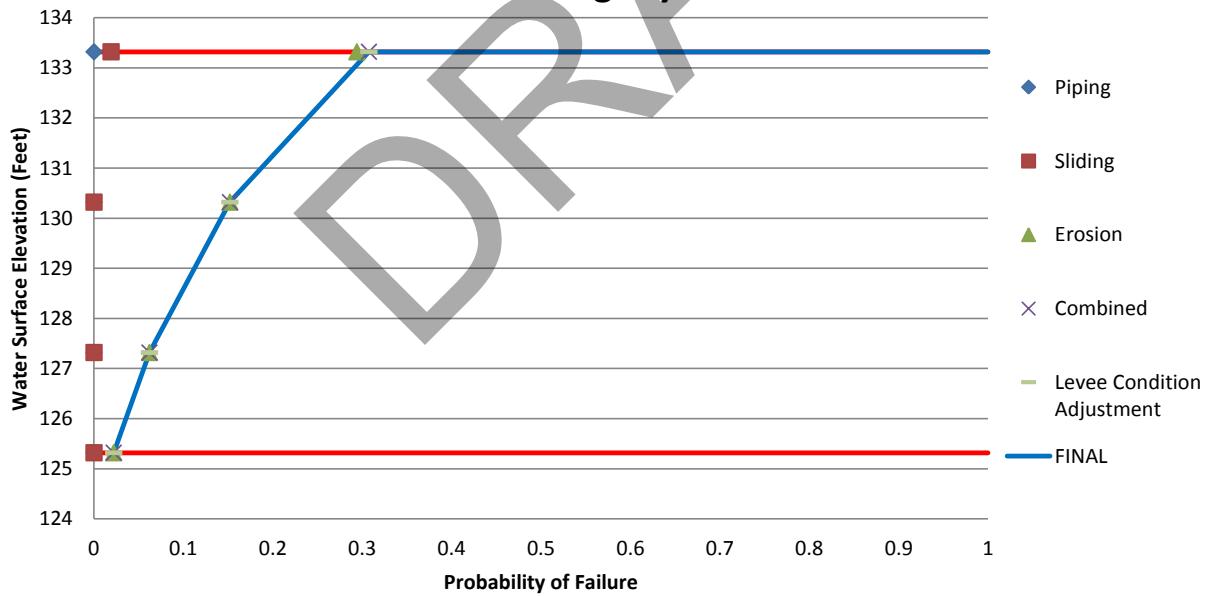
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



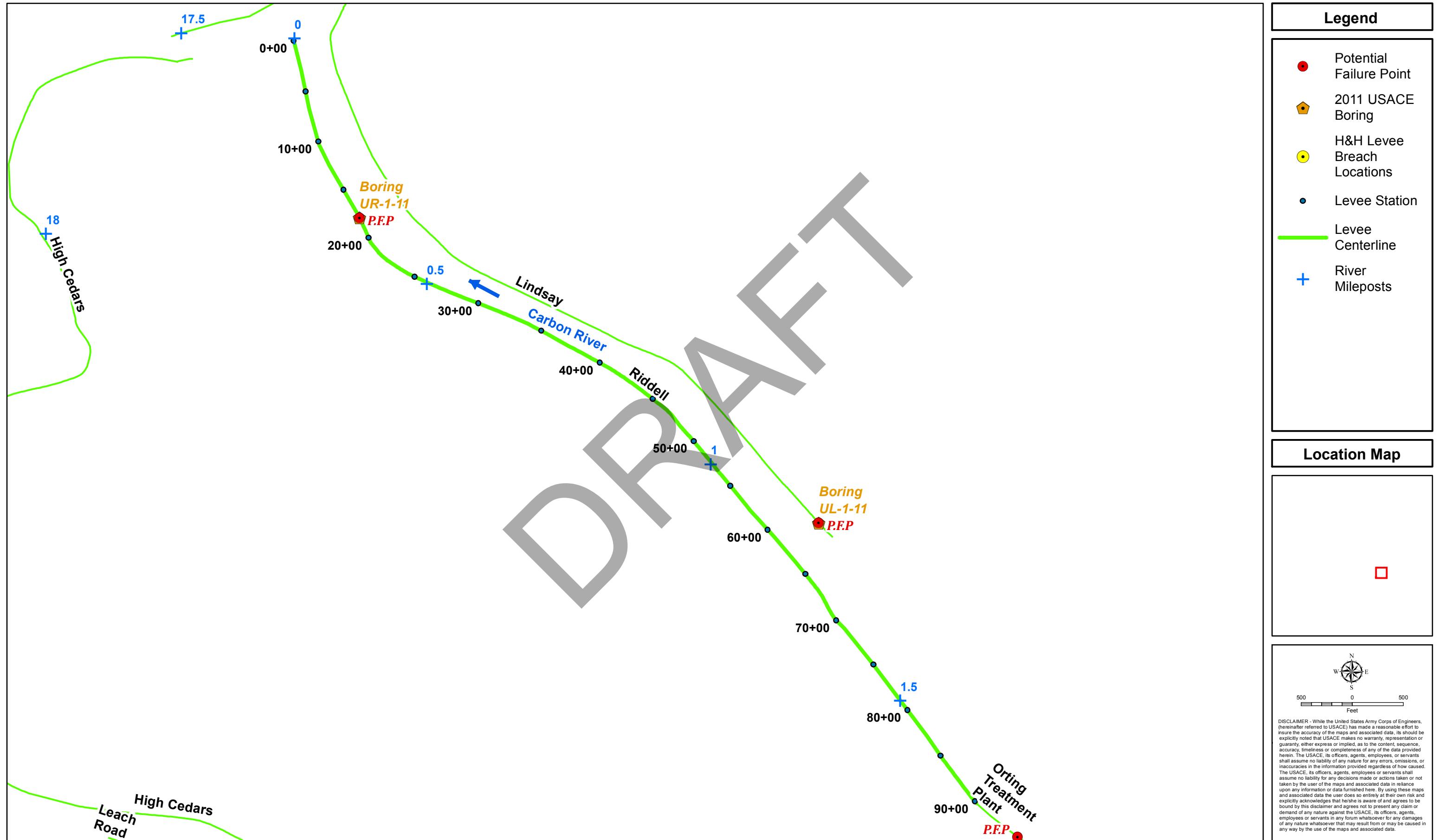
*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Riddell Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# Riddell Levee - Carbon River



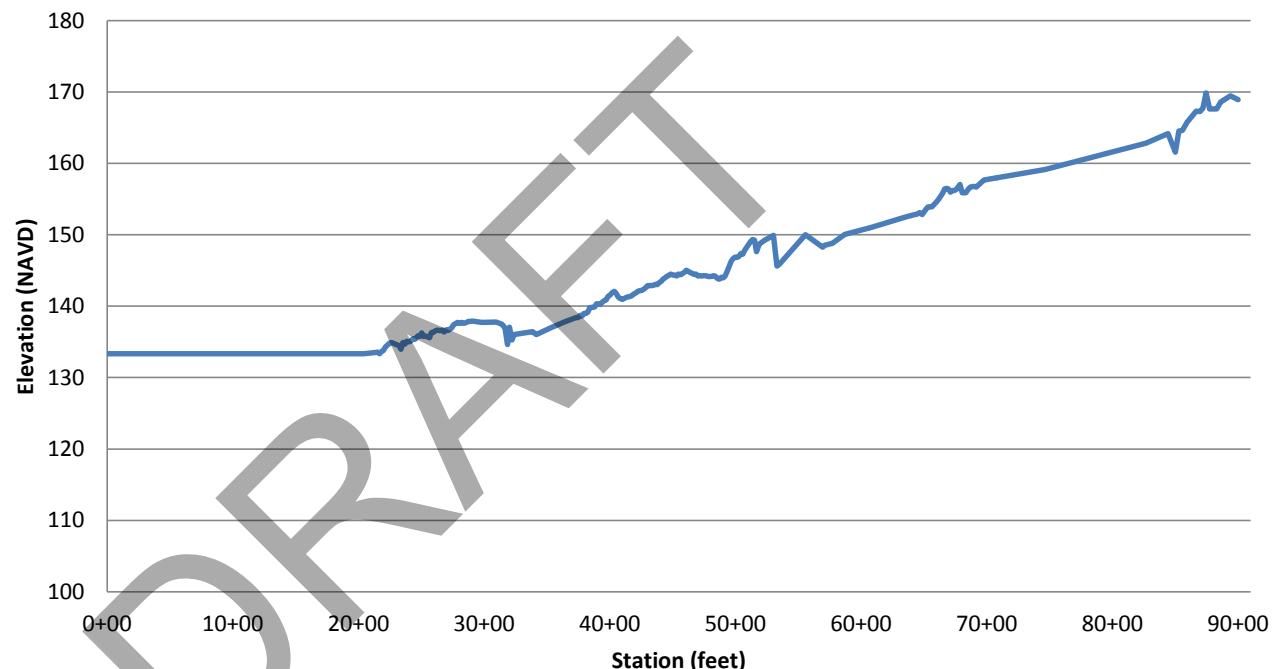
**Riddell Levee**

**Carbon River**

<b>Min</b>	133.32
<b>Max</b>	169.86

<b>Station Begin</b>	0+00
<b>Station End</b>	90+01

**Levee Profile**



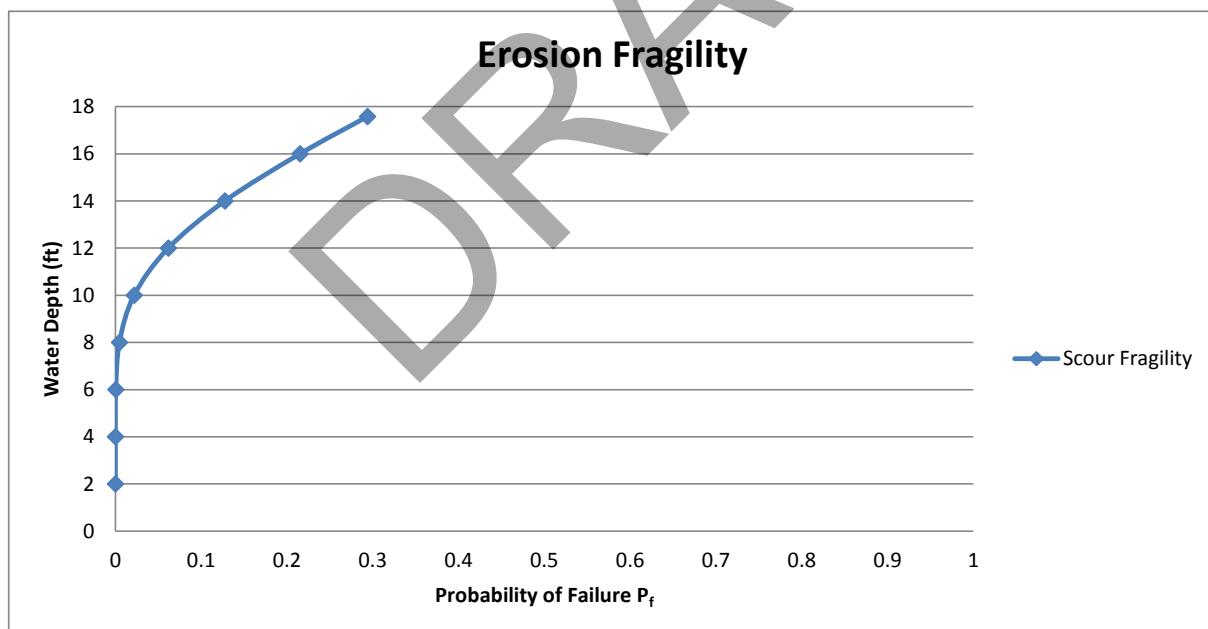
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Riddell Levee

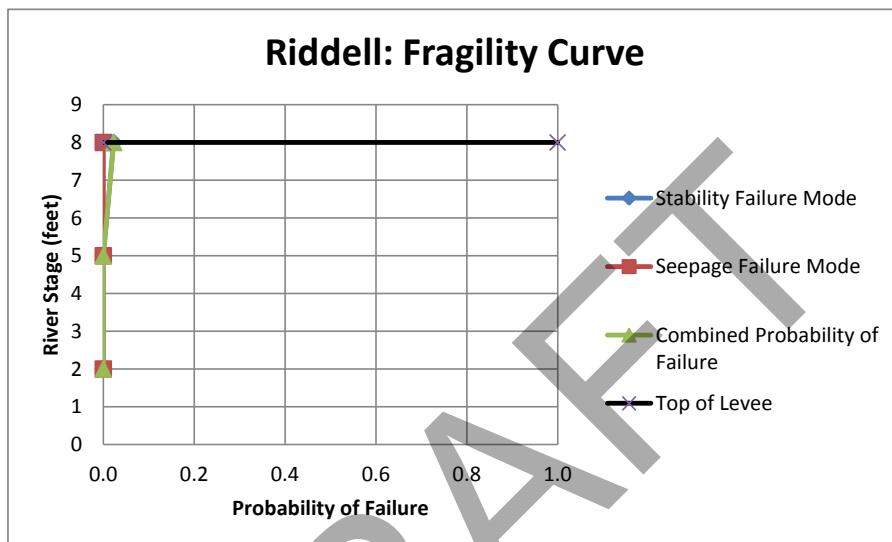
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0046	CV(s) =	0.1	0.00046
Manning's "n"	n =	0.055	CV(n) =	0.15	0.00825
Scouring Velocity		V <sub>crit</sub> =	14.23		2.85
			CV(v <sub>crit</sub> )		

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	2.909	0.1581139		-1.587346905	0.254950976	-6.22609	2.3911E-10
4	4.618	0.1581139		-1.125248785	0.254950976	-4.41359	5.0835E-06
6	6.051	0.1581139		-0.854938713	0.254950976	-3.35335	0.0003992
8	7.330	0.1581139		-0.663150665	0.254950976	-2.60109	0.00464639
10	8.506	0.1581139		-0.514388297	0.254950976	-2.0176	0.02181663
12	9.605	0.1581139		-0.392840592	0.254950976	-1.54085	0.06167694
14	10.644	0.1581139		-0.290073473	0.254950976	-1.13776	0.12760999
16	11.635	0.1581139		-0.201052544	0.254950976	-0.78859	0.21517497
17.58	12.389	0.1581139		-0.138270431	0.254950976	-0.54234	0.29379172



Riddell					
Fragility Curve					
Cross Section from STA 18+00					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 8' +					
8	0.023	8	2.1E-09	8	0.023
5	1.7E-06	5	1.6E-12	5	0.000
2	1.4E-11	2	0.0E+00	2	0.000



OVERTOPPING - 8' +	
Top of Levee	
8	0
8	1

Soil Unit	Stability	TOL		TOL - 3'		TOL - 6'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	1.29	0.36	1.55	0.18	1.74	0.07	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.30	0.36	1.55	0.18	1.74	0.07	yB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.29	0.36	1.55	0.18	1.74	0.07	yB +1SD
	log(K <sub>h</sub> )-1SD	1.30	0.36	1.55	0.19	1.74	0.07	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	1.23	0.36	1.52	0.18	1.74	0.07	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	$\gamma$ -1SD	1.28	0.31	1.54	0.16	1.75	0.06	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	$\gamma$ +1SD	1.31	0.40	1.55	0.25	1.74	0.08	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	$\phi$ -1SD	1.22	0.35	1.46	0.18	1.65	0.07	log(K <sub>h</sub> )-1SD
2	$\phi$ +1SD	1.37	0.37	1.64	0.20	1.84	0.08	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.32	0.38	1.56	0.20	1.75	0.08	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.10	0.35	1.43	0.18	1.70	0.12	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	1.23	(i)	1.52	(i)	1.74	(i)	Soil Unit 1
	log(K <sub>h</sub> )+1SD	1.31		1.56		1.74		Soil Unit 2
	$\gamma$ -1SD	1.27		1.53		1.72		Soil Unit 1
	$\gamma$ +1SD	1.32		1.57		1.76		Soil Unit 2
	$\gamma$ -1SD	1.22		1.46		1.64		Soil Unit 1
	$\gamma$ +1SD	1.37		1.64		1.84		Soil Unit 2

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Riddell
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Riddell Levee cross section from STA 18+00. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-1.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0	2.58	
2	52.6	1.5	1.5	-3	-1.3	0	0	0	0	0	2.36	
3	62.6	1.5	1.5	-3	-1.3	0	0	0	0	0	2.81	0.45
4	57.6	1	1.5	-3	-1.3	0	0	0	0	0	2.58	
5	57.6	2	1.5	-3	-1.3	0	0	0	0	0	2.59	0.00866
6	57.6	1.5	1	-3	-1.3	0	0	0	0	0	2.96	
7	57.6	1.5	2	-3	-1.3	0	0	0	0	0	2.31	-0.65109
8	57.6	1.5	1.5	-4	-1.3	0	0	0	0	0	2.61	
9	57.6	1.5	1.5	-2	-1.3	0	0	0	0	0	2.46	-0.14692
10	57.6	1.5	1.5	-3	-2.3	0	0	0	0	0	2.46	
11	57.6	1.5	1.5	-3	-0.3	0	0	0	0	0	2.66	0.19677
12	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		

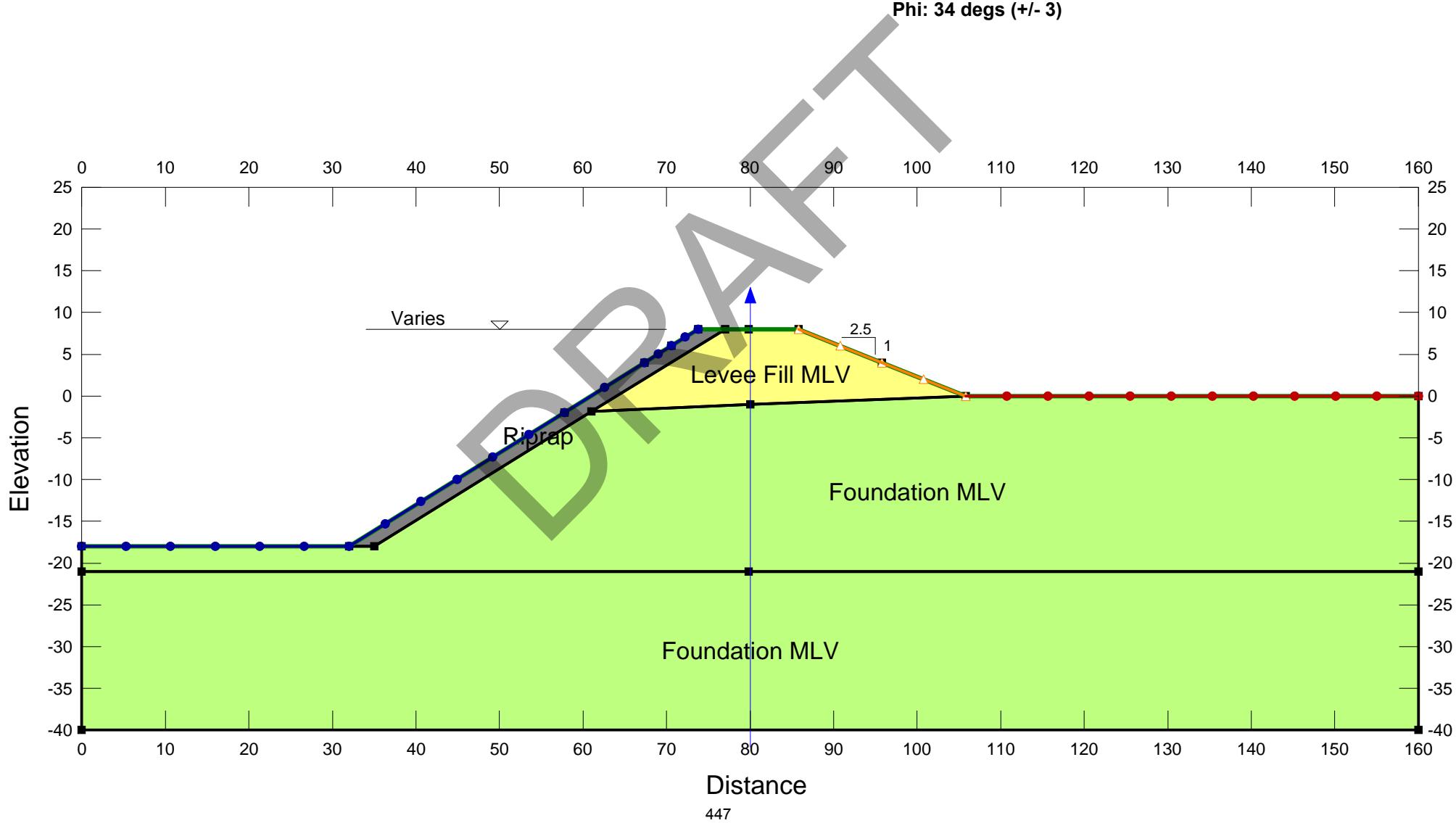
Standard deviation of F,	$\sigma_F$	0.414
Coefficient of variation of F,	$V_F$	0.160
Log normal reliability index,	$\beta_{LN}$	5.873
Reliability		1.000
Probability of failure		2.1E-09

Riddell Levee  
Carbon River  
STA 18+00

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

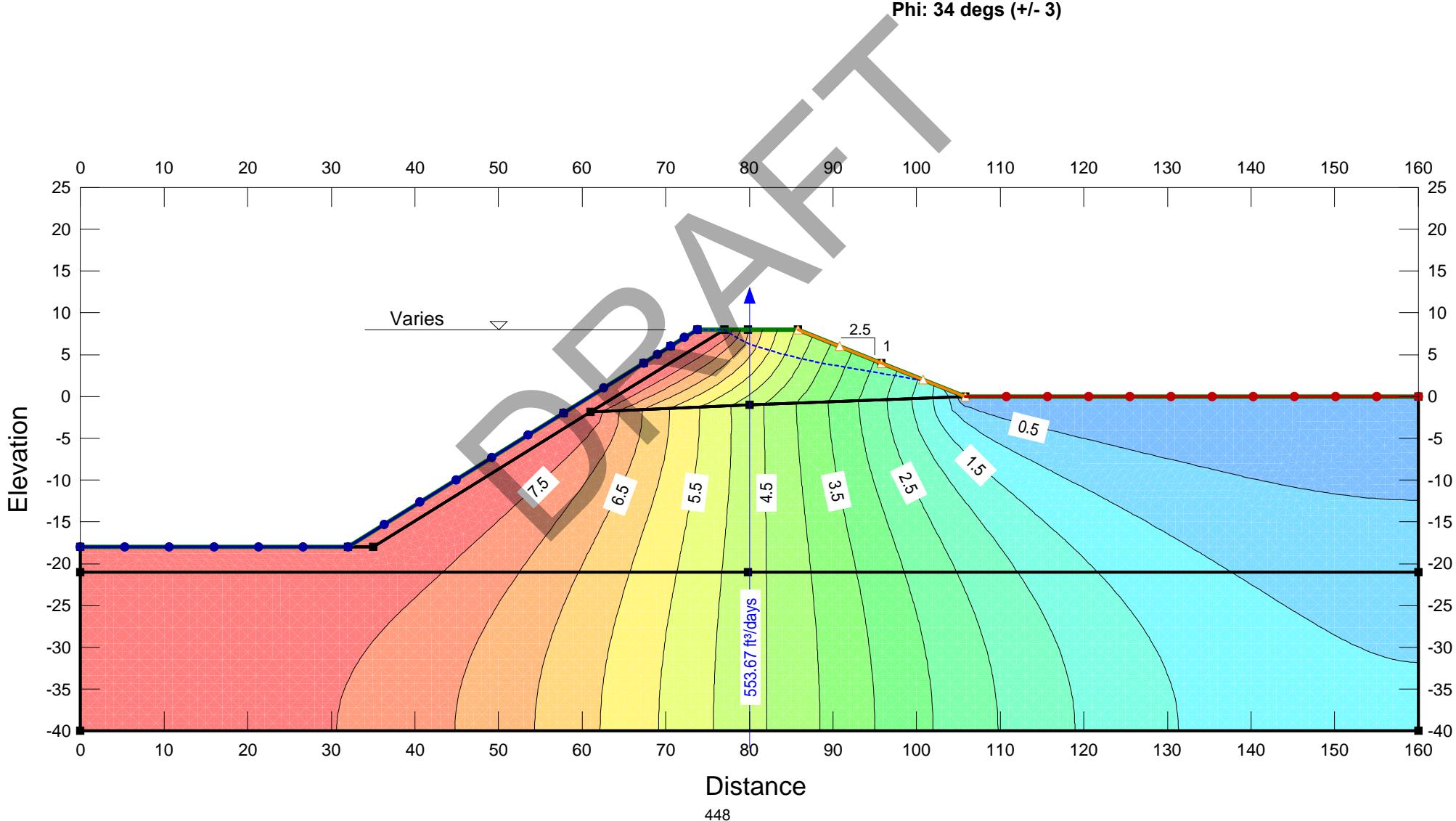


Riddell Levee  
Carbon River  
STA 23+17

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

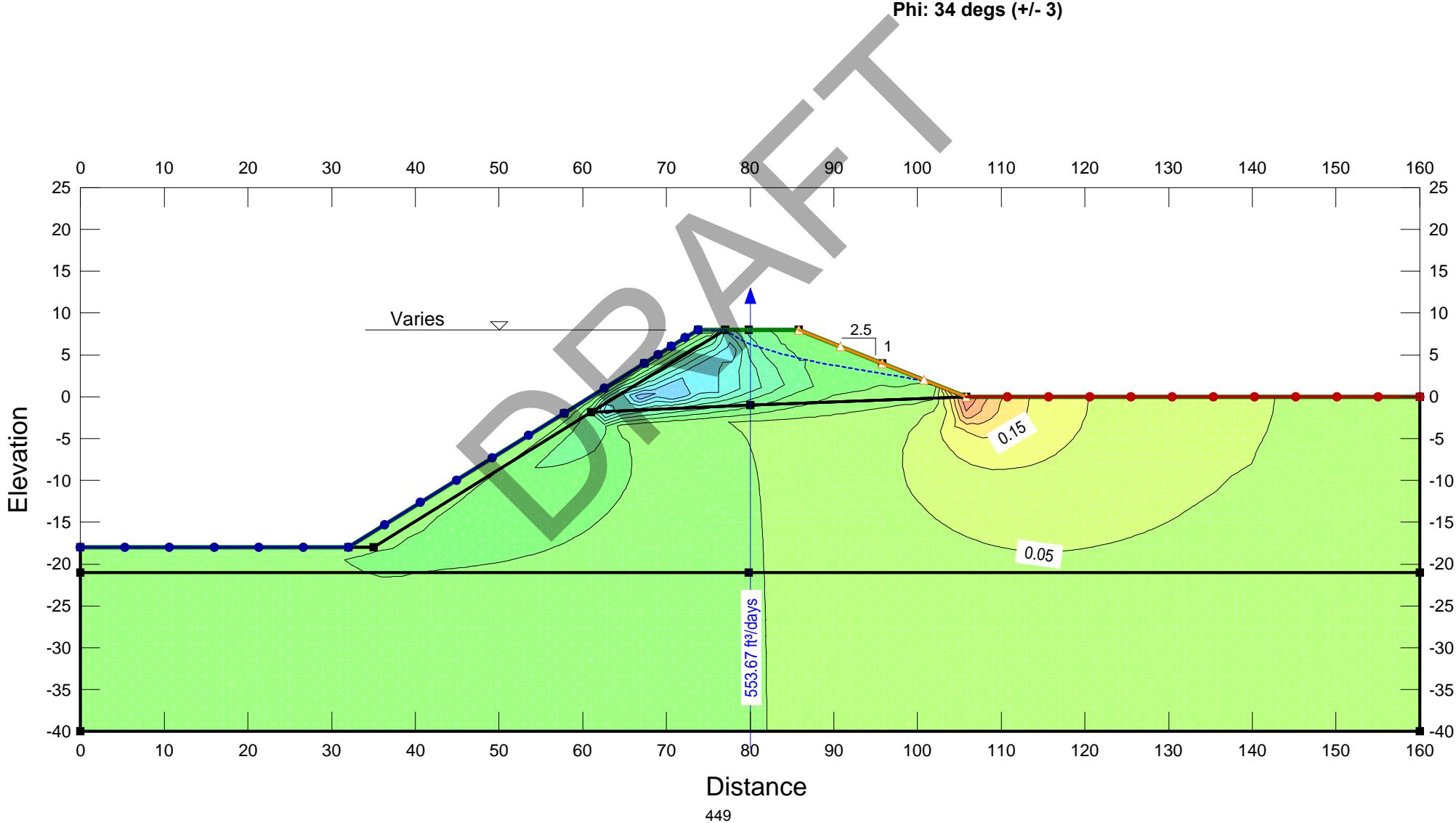


Riddell Levee  
Carbon River  
STA 23+17

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



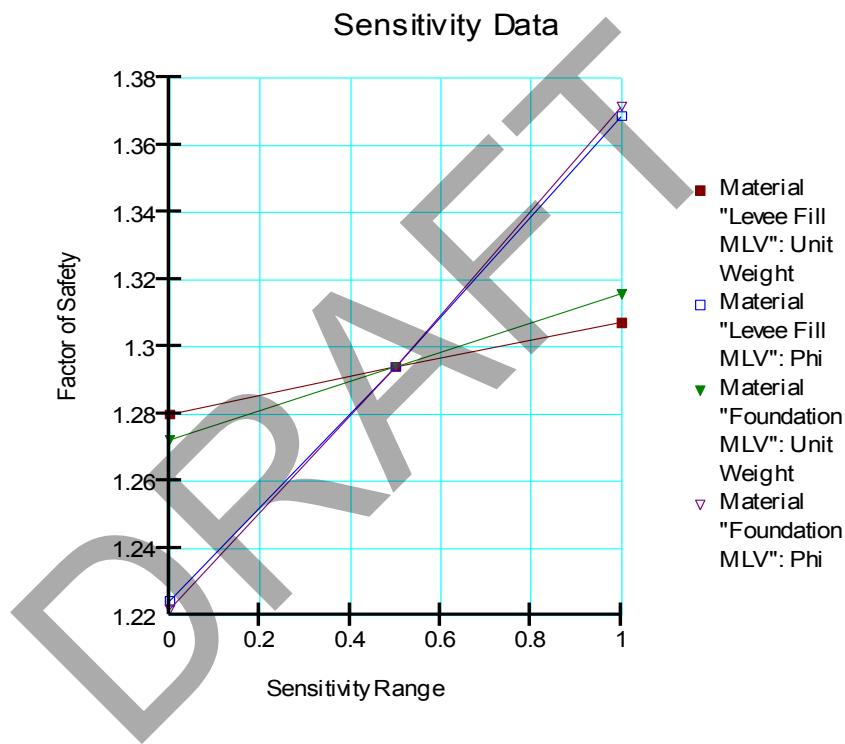
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Riddell
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Riddell Levee cross section from STA 18+00. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	log( $K_h$ ) (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	log( $K_h$ ) (Foundation)	-1.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	34	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-1.3	120	34	0	0	1.29	
2	1	-3	120	33	1.5	-1.3	120	34	0	0	1.30	
3	2	-3	120	33	1.5	-1.3	120	34	0	0	1.29	-0.01
4	1.5	-4	120	33	1.5	-1.3	120	34	0	0	1.30	
5	1.5	-2	120	33	1.5	-1.3	120	34	0	0	1.23	-0.07
6	1.5	-3	115	33	1.5	-1.3	120	34	0	0	1.28	
7	1.5	-3	125	33	1.5	-1.3	120	34	0	0	1.31	0.02725
8	1.5	-3	120	30	1.5	-1.3	120	34	0	0	1.22	
9	1.5	-3	120	36	1.5	-1.3	120	34	0	0	1.37	0.14443
10	1.5	-3	120	33	1	-1.3	120	34	0	0	1.32	
11	1.5	-3	120	33	2	-1.3	120	34	0	0	1.10	-0.22
12	1.5	-3	120	33	1.5	-2.3	120	34	0	0	1.23	
13	1.5	-3	120	33	1.5	-0.3	120	34	0	0	1.31	0.08
14	1.5	-3	120	33	1.5	-1.3	115	34	0	0	1.27	
15	1.5	-3	120	33	1.5	-1.3	125	34	0	0	1.32	0.04325
16	1.5	-3	120	33	1.5	-1.3	120	31	0	0	1.22	
17	1.5	-3	120	33	1.5	-1.3	120	37	0	0	1.37	0.14977
18	1.5	-3	120	33	1.5	-1.3	120	34	0	0		
19	1.5	-3	120	33	1.5	-1.3	120	34	0	0		0
20	1.5	-3	120	33	1.5	-1.3	120	34	0	0		
21	1.5	-3	120	33	1.5	-1.3	120	34	0	0		0

Standard deviation of F,	$\sigma_F$	0.163
Coefficient of variation of F,	$V_F$	0.126
Log normal reliability index,	$\beta_{LN}$	1.998
Reliability		0.977
Probability of failure		0.023

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.2798753	1.2243008	1.2723871	1.2217704
0.5	1.2940719	1.2940719	1.2940719	1.2940719
1	1.3071296	1.3687324	1.3156392	1.3715394

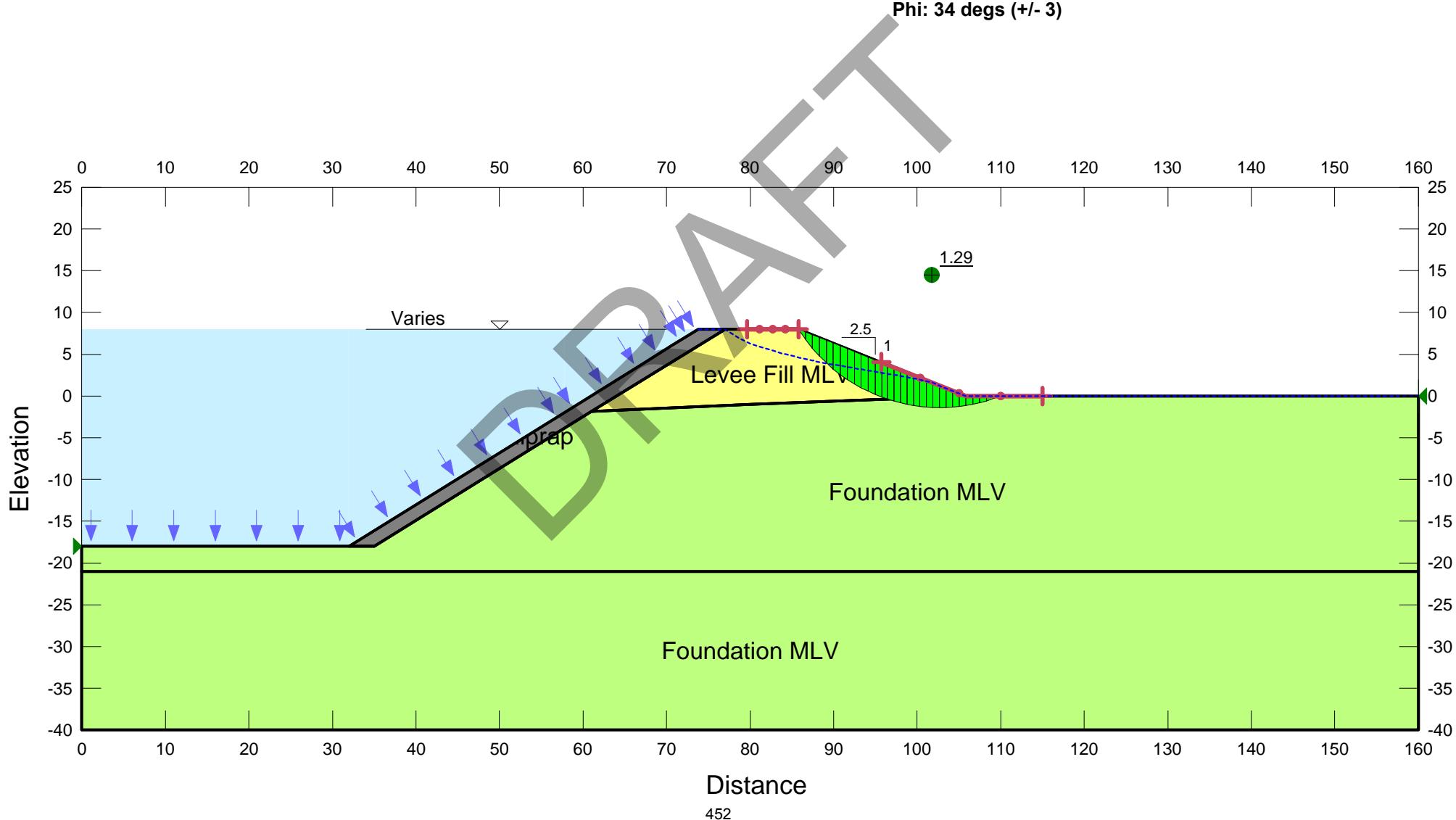


Riddell Levee  
Carbon River  
STA 18+00

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Riddell
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Riddell Levee cross section from STA 18+00. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0	5.04	
2	52.6	1.5	1.5	-3	-1.3	0	0	0	0	0	4.60	
3	62.6	1.5	1.5	-3	-1.3	0	0	0	0	0	5.48	0.87476
4	57.6	1	1.5	-3	-1.3	0	0	0	0	0	4.96	
5	57.6	2	1.5	-3	-1.3	0	0	0	0	0	5.04	0.08136
6	57.6	1.5	1	-3	-1.3	0	0	0	0	0	5.84	
7	57.6	1.5	2	-3	-1.3	0	0	0	0	0	3.76	-2.0838
8	57.6	1.5	1.5	-4	-1.3	0	0	0	0	0	5.08	
9	57.6	1.5	1.5	-2	-1.3	0	0	0	0	0	4.71	-0.37104
10	57.6	1.5	1.5	-3	-2.3	0	0	0	0	0	4.70	
11	57.6	1.5	1.5	-3	-0.3	0	0	0	0	0	5.13	0.42343
12	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		

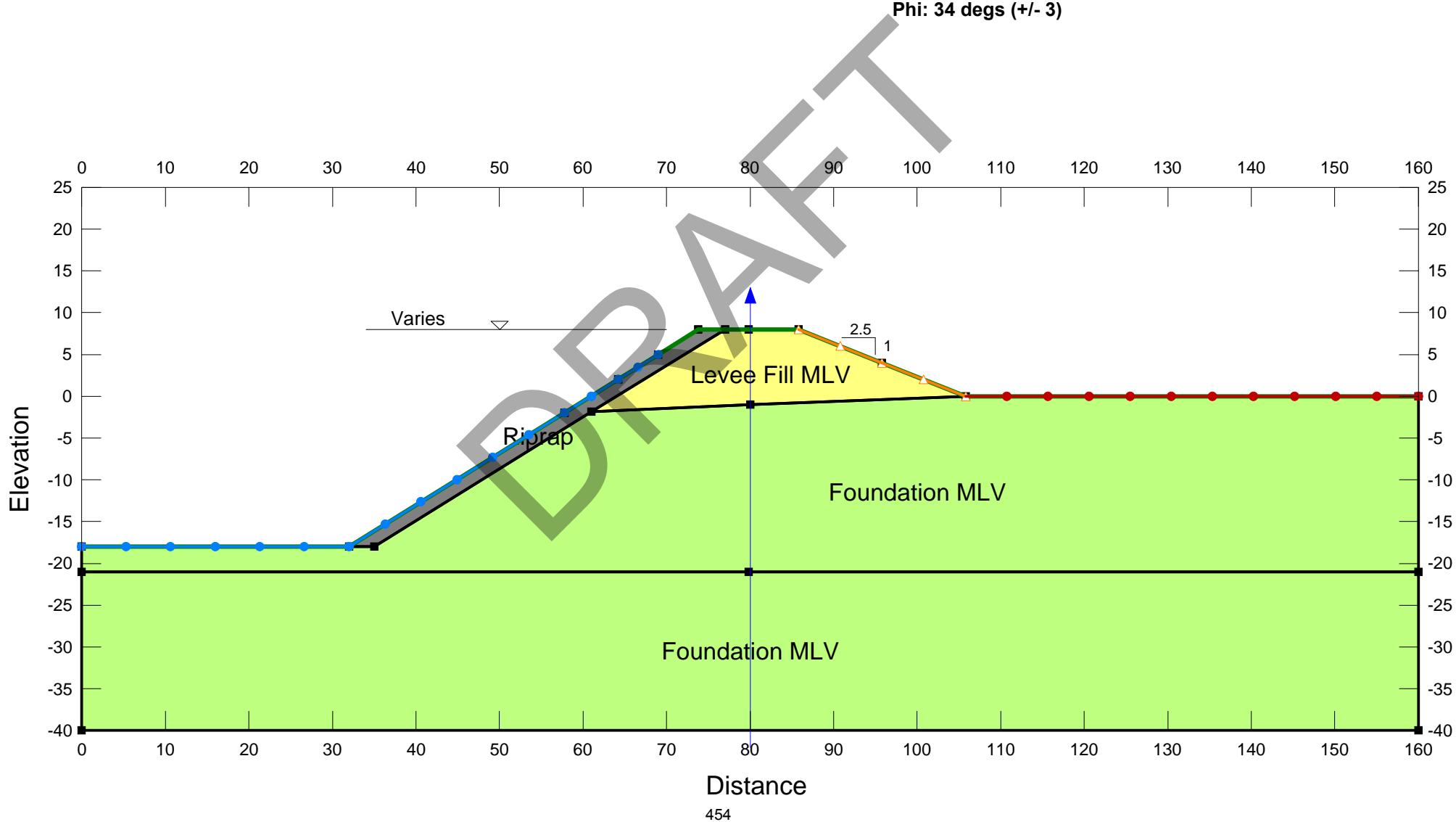
Standard deviation of F,	$\sigma_F$	1.165
Coefficient of variation of F,	$V_F$	0.231
Log normal reliability index,	$\beta_{LN}$	6.971
Reliability		1.000
Probability of failure		1.6E-12

Riddell Levee  
Carbon River  
STA 18+00

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

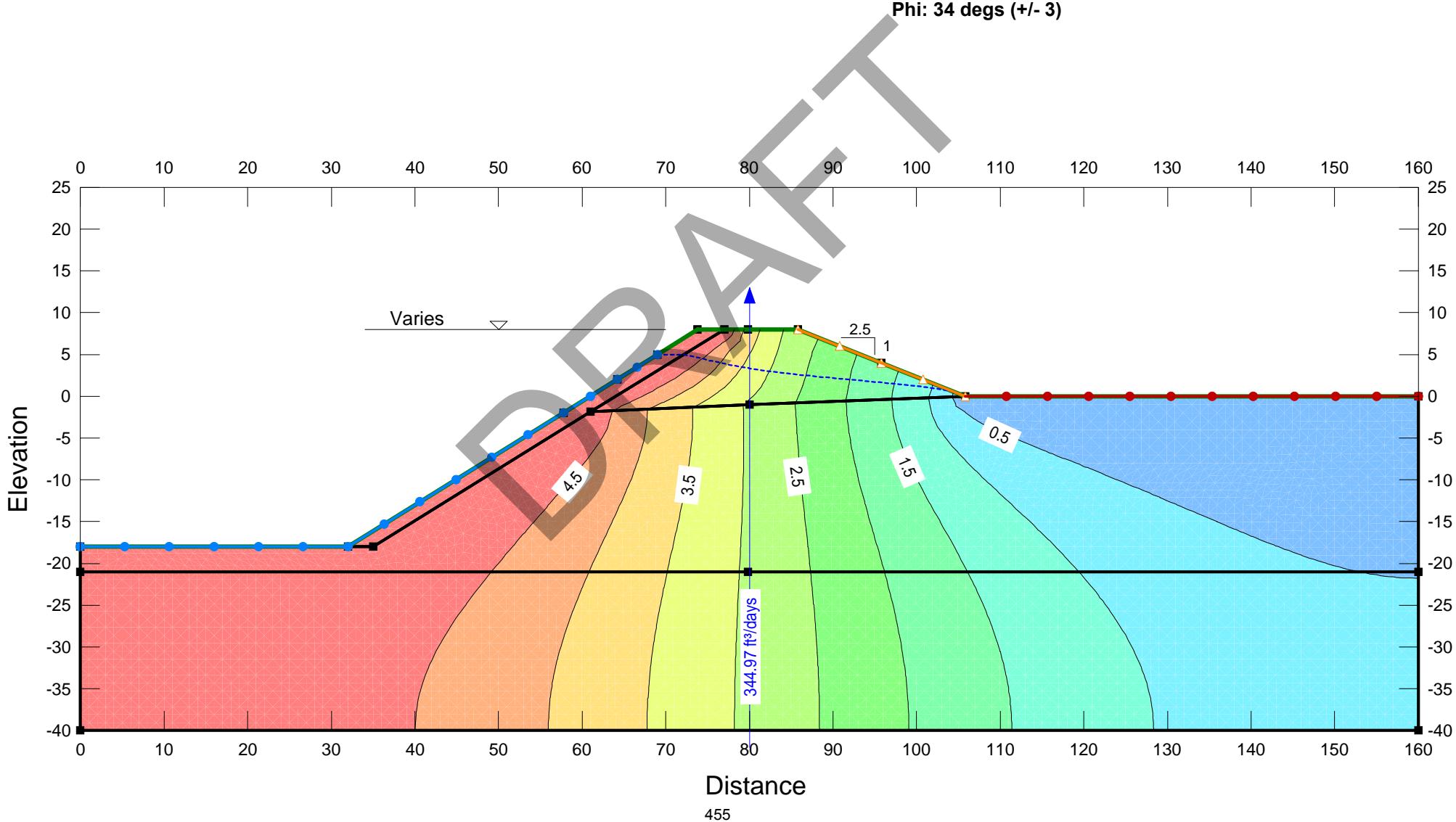


Riddell Levee  
Carbon River  
STA 23+17

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

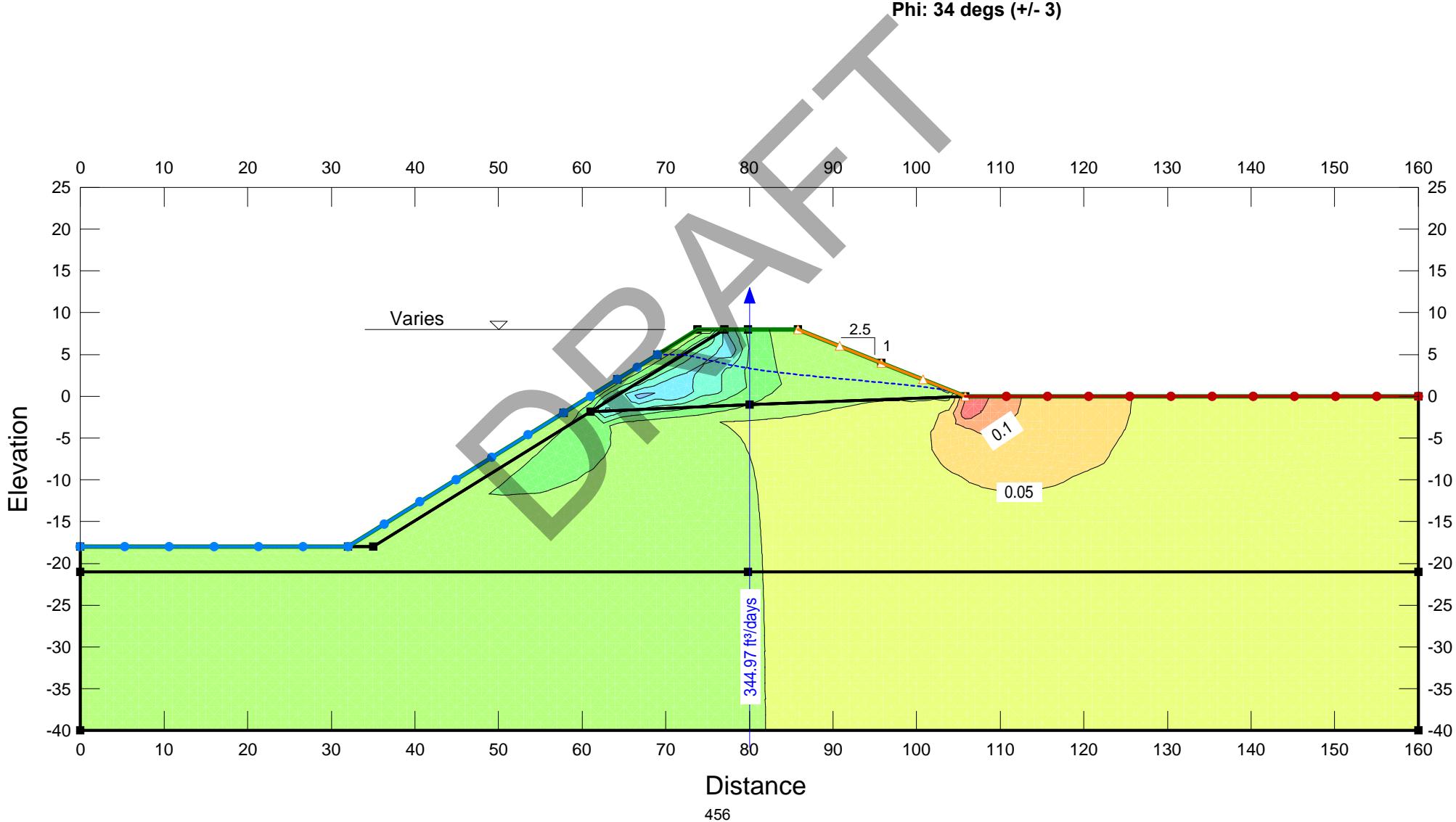


Riddell Levee  
Carbon River  
STA 23+17

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



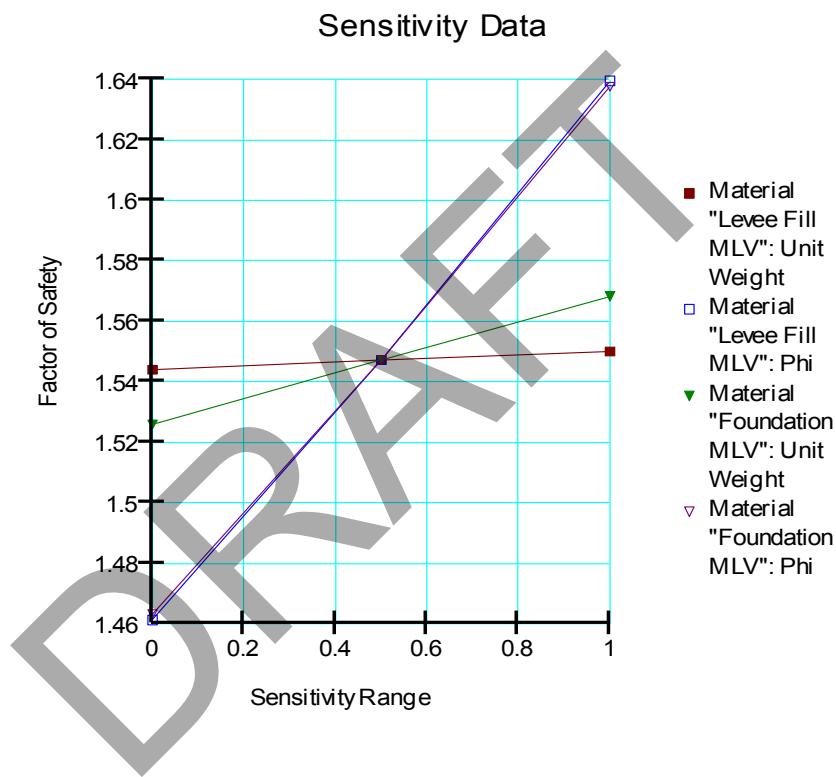
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Riddell
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Riddell Levee cross section from STA 18+00. Water Surface Elevation is 3 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	34	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-1.3	120	34	0	0	1.55	
2	1	-3	120	33	1.5	-1.3	120	34	0	0	1.55	
3	2	-3	120	33	1.5	-1.3	120	34	0	0	1.55	0
4	1.5	-4	120	33	1.5	-1.3	120	34	0	0	1.55	
5	1.5	-2	120	33	1.5	-1.3	120	34	0	0	1.52	-0.03
6	1.5	-3	115	33	1.5	-1.3	120	34	0	0	1.54	
7	1.5	-3	125	33	1.5	-1.3	120	34	0	0	1.55	0.00609
8	1.5	-3	120	30	1.5	-1.3	120	34	0	0	1.46	
9	1.5	-3	120	36	1.5	-1.3	120	34	0	0	1.64	0.17816
10	1.5	-3	120	33	1	-1.3	120	34	0	0	1.56	
11	1.5	-3	120	33	2	-1.3	120	34	0	0	1.43	-0.13
12	1.5	-3	120	33	1.5	-2.3	120	34	0	0	1.52	
13	1.5	-3	120	33	1.5	-0.3	120	34	0	0	1.56	0.04
14	1.5	-3	120	33	1.5	-1.3	115	34	0	0	1.53	
15	1.5	-3	120	33	1.5	-1.3	125	34	0	0	1.57	0.04224
16	1.5	-3	120	33	1.5	-1.3	120	31	0	0	1.46	
17	1.5	-3	120	33	1.5	-1.3	120	37	0	0	1.64	0.17425
18	1.5	-3	120	33	1.5	-1.3	120	34	0	0		
19	1.5	-3	120	33	1.5	-1.3	120	34	0	0		0
20	1.5	-3	120	33	1.5	-1.3	120	34	0	0		
21	1.5	-3	120	33	1.5	-1.3	120	34	0	0		0

Standard deviation of F,	$\sigma_F$	0.144
Coefficient of variation of F,	$V_F$	0.093
Log normal reliability index,	$\beta_{LN}$	4.642
Reliability		1.000
Probability of failure		1.7E-06

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.543965	1.4612881	1.5259801	1.4632637
0.5	1.547138	1.547138	1.547138	1.547138
1	1.5500519	1.6394464	1.5682222	1.6375093

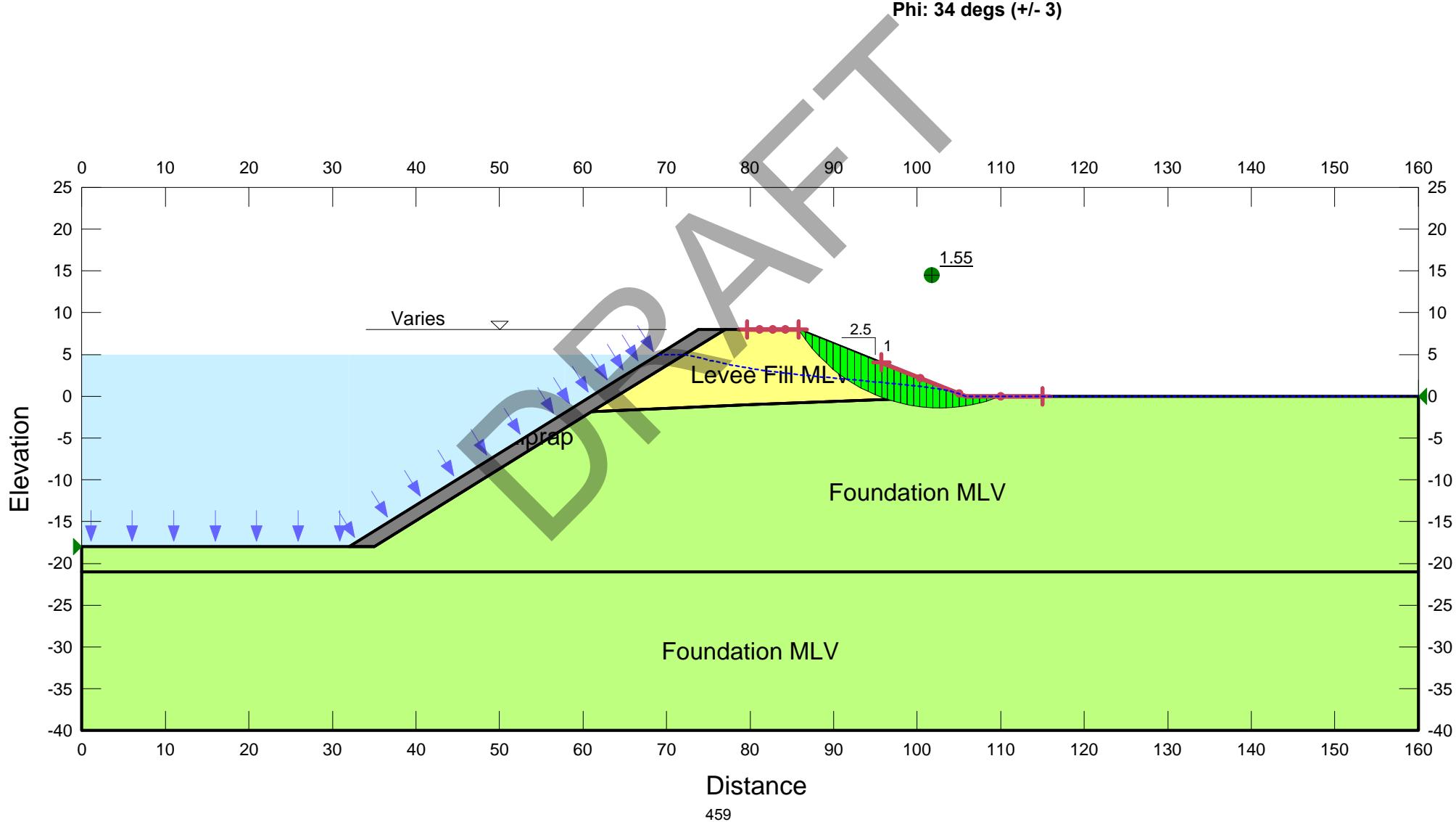


Riddell Levee  
Carbon River  
STA 18+00

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Riddell
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Riddell Levee cross section from STA 18+00. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3	cm/s	1
5	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0	12.64	
2	52.6	1.5	1.5	-3	-1.3	0	0	0	0	0	11.55	
3	62.6	1.5	1.5	-3	-1.3	0	0	0	0	0	13.74	2.19529
4	57.6	1	1.5	-3	-1.3	0	0	0	0	0	13.19	
5	57.6	2	1.5	-3	-1.3	0	0	0	0	0	13.19	0
6	57.6	1.5	1	-3	-1.3	0	0	0	0	0	15.38	
7	57.6	1.5	2	-3	-1.3	0	0	0	0	0	11.54	-3.84615
8	57.6	1.5	1.5	-4	-1.3	0	0	0	0	0	13.19	
9	57.6	1.5	1.5	-2	-1.3	0	0	0	0	0	11.54	-1.64835
10	57.6	1.5	1.5	-3	-2.3	0	0	0	0	0	11.54	
11	57.6	1.5	1.5	-3	-0.3	0	0	0	0	0	7.69	-3.84615
12	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3	-1.3	0	0	0	0	0		

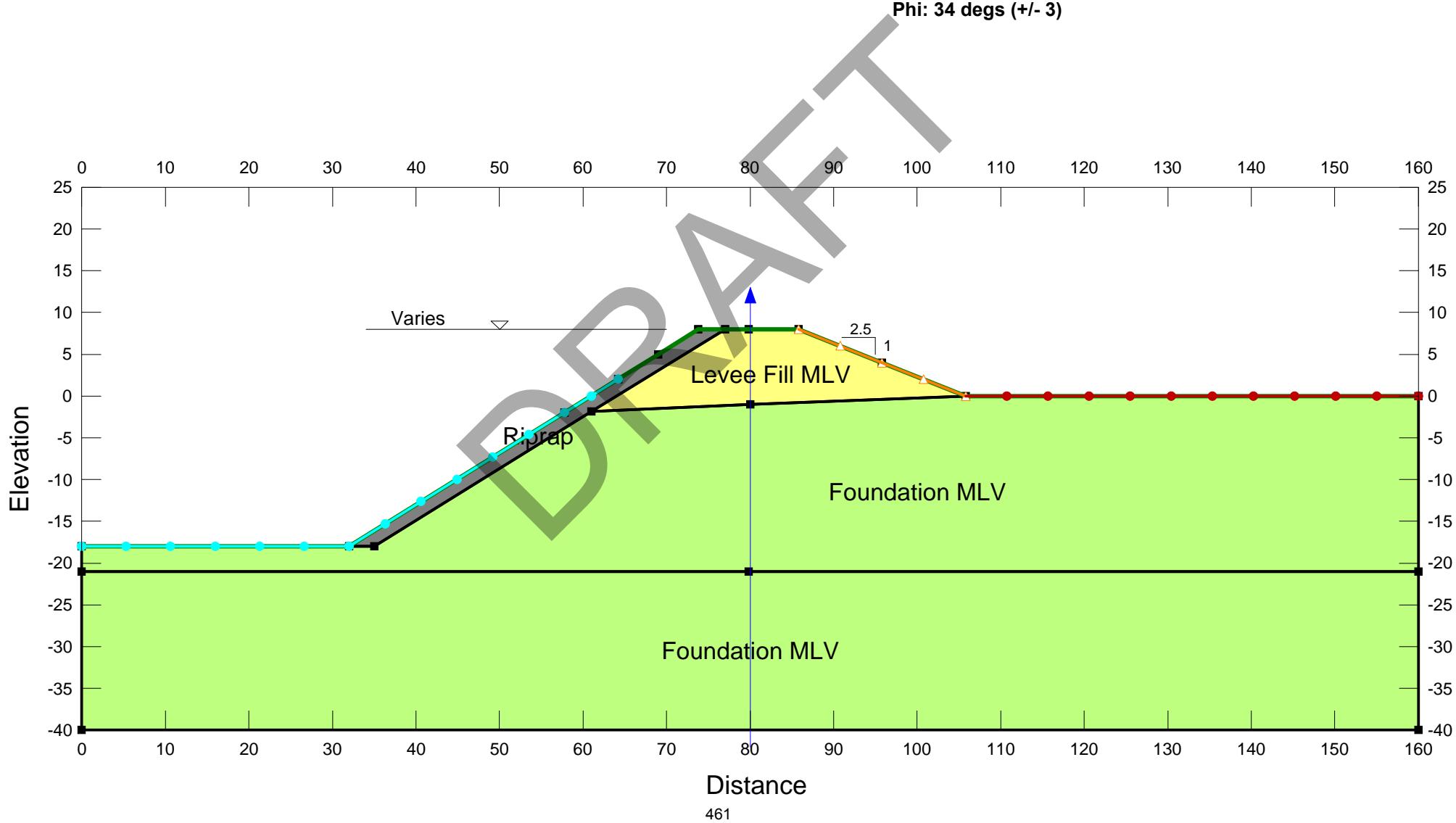
Standard deviation of F,	$\sigma_F$	3.046
Coefficient of variation of F,	$V_F$	0.241
Log normal reliability index,	$\beta_{LN}$	10.563
Reliability		1.000
Probability of failure		0.0E+00

Riddell Levee  
Carbon River  
STA 18+00

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

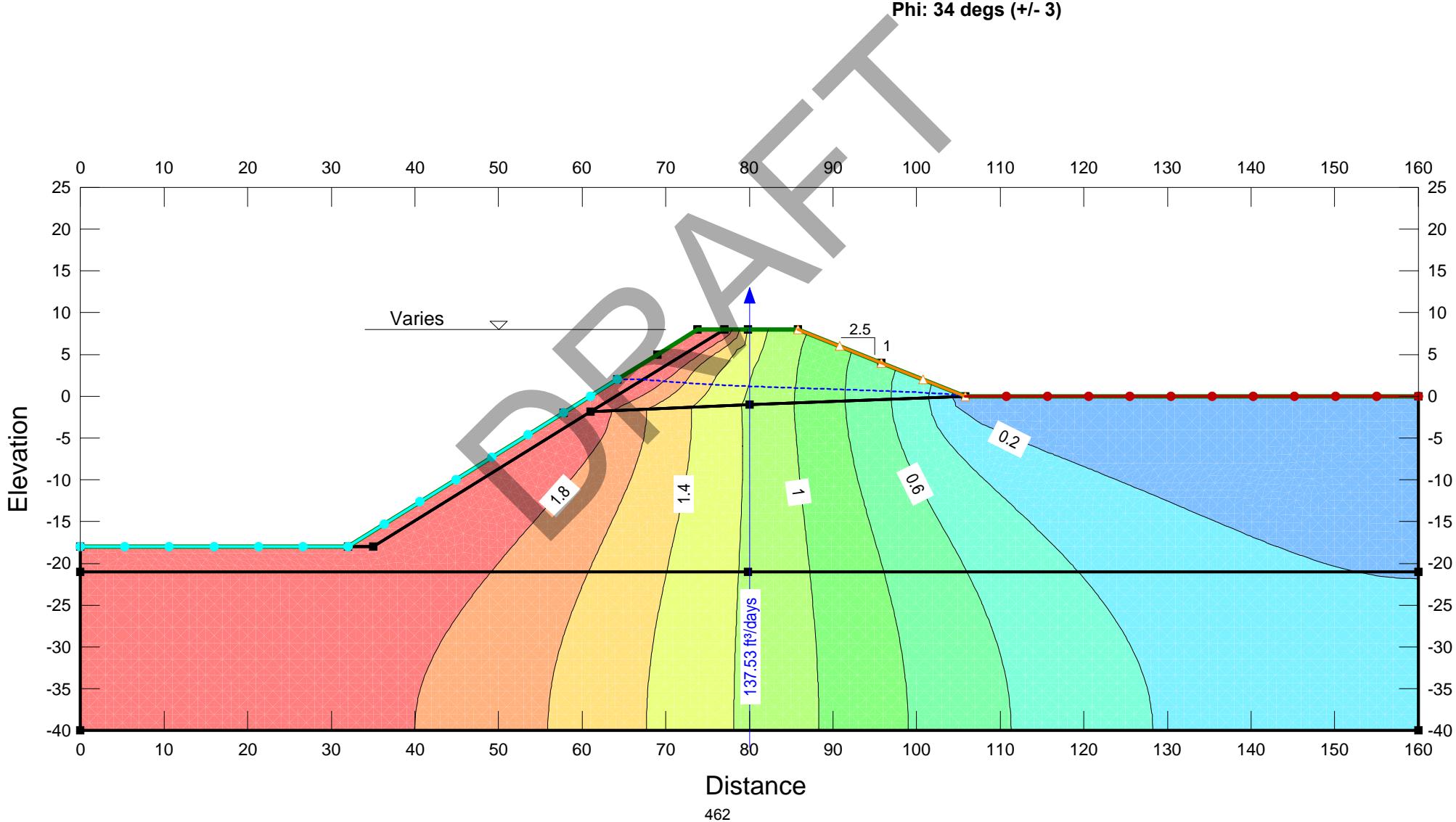


Riddell Levee  
Carbon River  
STA 23+17

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

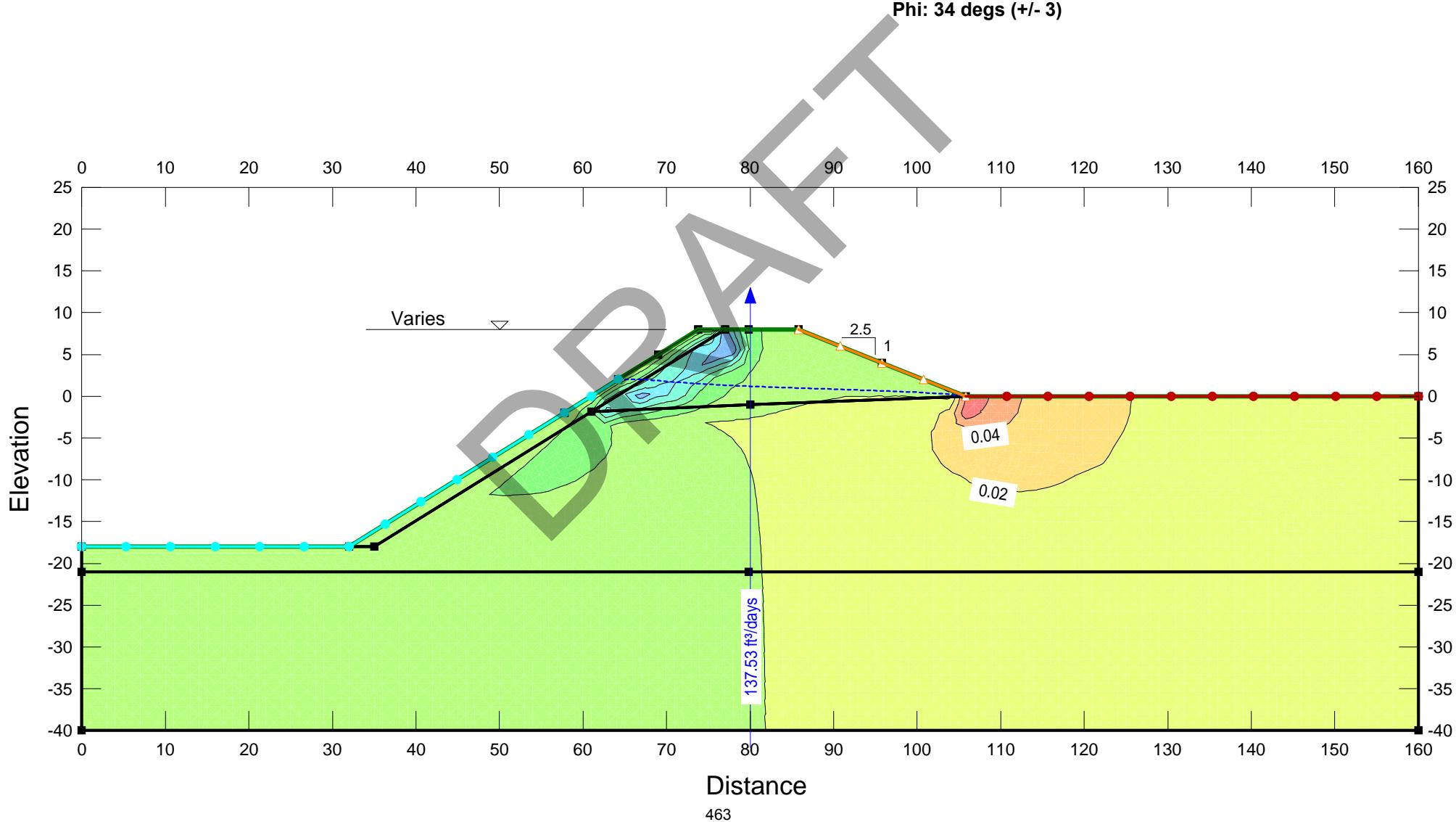


Riddell Levee  
Carbon River  
STA 23+17

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



**Taylor's series method spreadsheet**

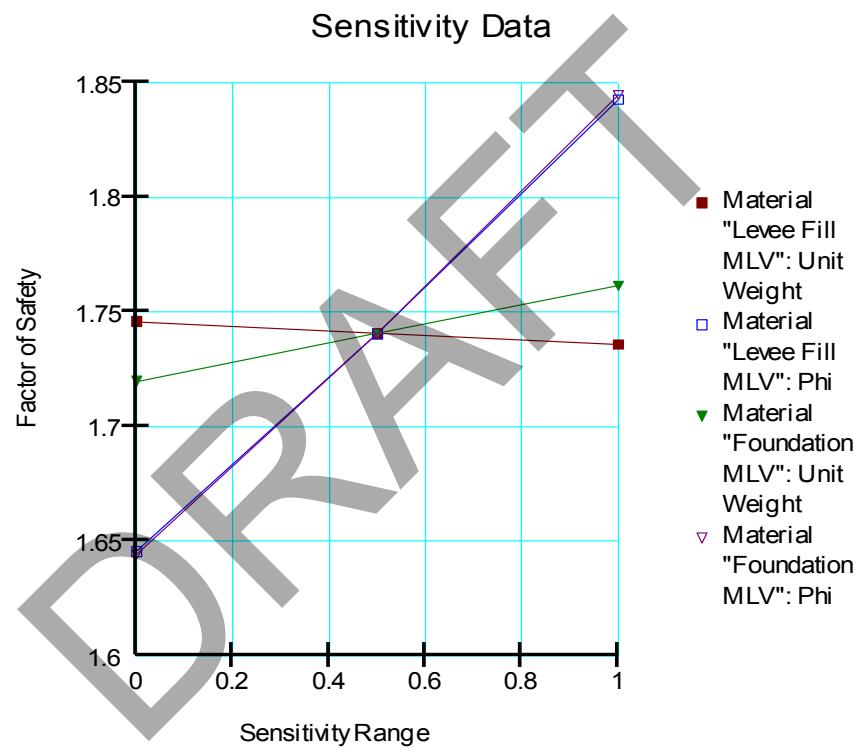
Project	Puyallup General Investigation
Feature	Riddell
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Riddell Levee cross section from STA 18+00. Water Surface Elevation is 6 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	33	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-1.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	34	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3	120	33	1.5	-1.3	120	34	0	0	1.74	
2	1	-3	120	33	1.5	-1.3	120	34	0	0	1.74	
3	2	-3	120	33	1.5	-1.3	120	34	0	0	1.74	0
4	1.5	-4	120	33	1.5	-1.3	120	34	0	0	1.74	
5	1.5	-2	120	33	1.5	-1.3	120	34	0	0	1.74	0
6	1.5	-3	115	33	1.5	-1.3	120	34	0	0	1.75	
7	1.5	-3	125	33	1.5	-1.3	120	34	0	0	1.74	-0.01006
8	1.5	-3	120	30	1.5	-1.3	120	34	0	0	1.65	
9	1.5	-3	120	36	1.5	-1.3	120	34	0	0	1.84	0.19696
10	1.5	-3	120	33	1	-1.3	120	34	0	0	1.75	
11	1.5	-3	120	33	2	-1.3	120	34	0	0	1.70	-0.05
12	1.5	-3	120	33	1.5	-2.3	120	34	0	0	1.74	
13	1.5	-3	120	33	1.5	-0.3	120	34	0	0	1.74	0
14	1.5	-3	120	33	1.5	-1.3	115	34	0	0	1.72	
15	1.5	-3	120	33	1.5	-1.3	125	34	0	0	1.76	0.04153
16	1.5	-3	120	33	1.5	-1.3	120	31	0	0	1.64	
17	1.5	-3	120	33	1.5	-1.3	120	37	0	0	1.84	0.20025
18	1.5	-3	120	33	1.5	-1.3	120	34	0	0		
19	1.5	-3	120	33	1.5	-1.3	120	34	0	0		0
20	1.5	-3	120	33	1.5	-1.3	120	34	0	0		
21	1.5	-3	120	33	1.5	-1.3	120	34	0	0		0

Standard deviation of F,	$\sigma_F$	0.144
Coefficient of variation of F,	$V_F$	0.083
Log normal reliability index,	$\beta_{LN}$	6.659
Reliability		1.000
Probability of failure		1.4E-11

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.7458846	1.6455766	1.7198564	1.6443579
0.5	1.7406444	1.7406444	1.7406444	1.7406444
1	1.7358216	1.8425372	1.7613853	1.8446094

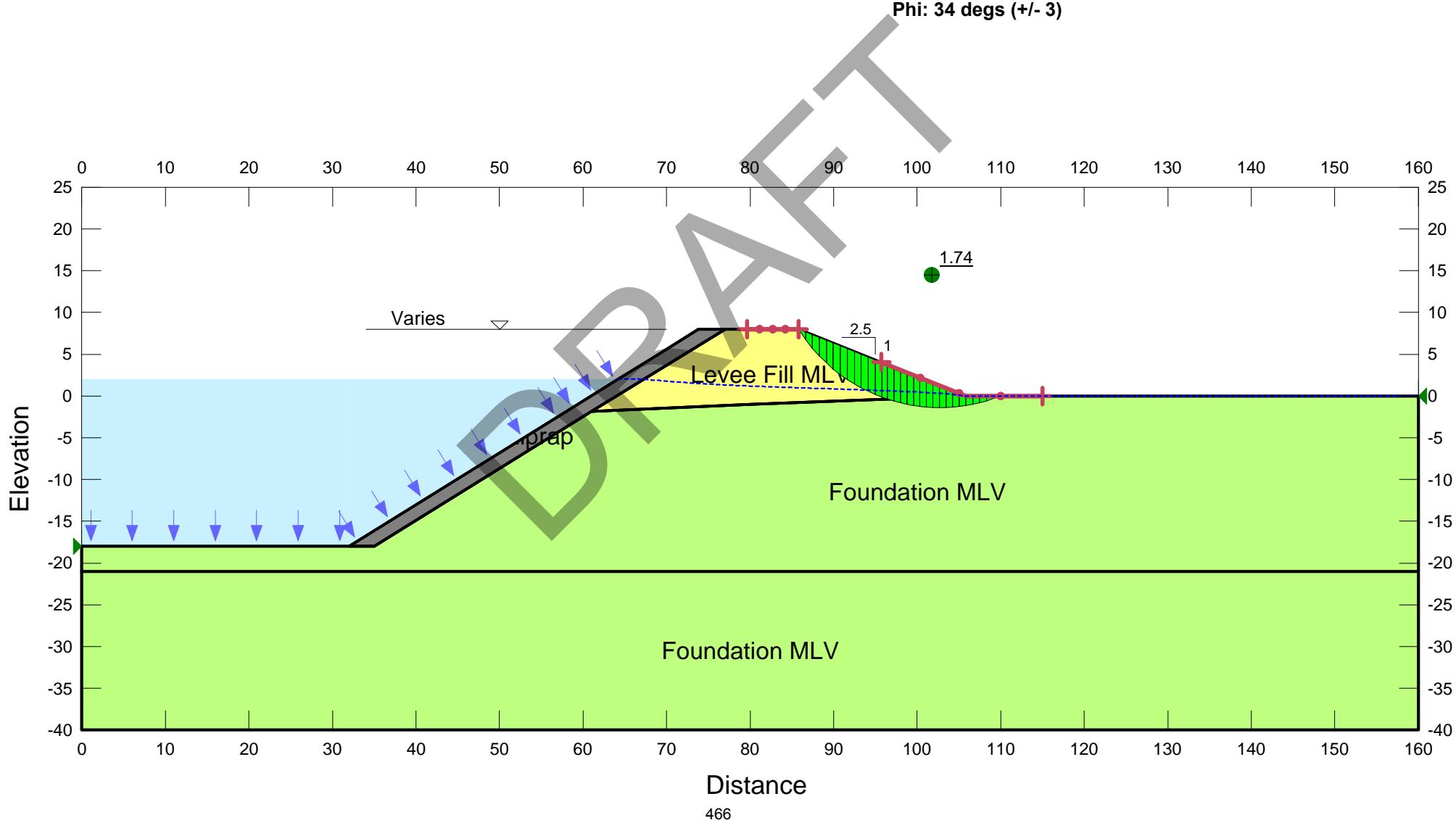


Riddell Levee  
Carbon River  
STA 18+00

Levee Fill (SM)  
 $\log(K\text{-Sat})$ : -3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 33 degs (+/- 3)

Riprap  
 $\log(K\text{-Sat})$ : 0 cm/s  
KH/KV Ratio: 1.0  
Unit Weight: 115 pcf  
Phi: 45 degs

Levee Foundation (SP)  
 $\log(K\text{-Sat})$ : -1.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	River Grove
<b>Station:</b>	5+00

#### Levee Condition Factor

Levee Condition Factor	2
------------------------	---

**Remarks:** Levee is deemed a 2 because the levee is rated unacceptable per USACE guidance. Extensive vegetation maintenance issues were noted.

#### Levee Geometry

R	W	L	H
Crown Width (W)			5 Feet
Landward Levee Height (H)			2.8 Feet
Riverward Slope (R)			2.85 H:1V
Landward Slope (L)			2.85 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	2.8 Feet
Breach Width at Top of Levee	62.7 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.55 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

Homogeneous Foundation
Interbedded Foundation
Layered Foundation

**Remarks:** Levee foundation material is unknown.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
Loose / Soft		Low
Medium		Medium
Dense / Stiff		High

**Remarks:** Levee embankment material is unknown.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
50.91	1.00
50.91	0.00
49.91	0.00
48.91	0.00
48.11	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

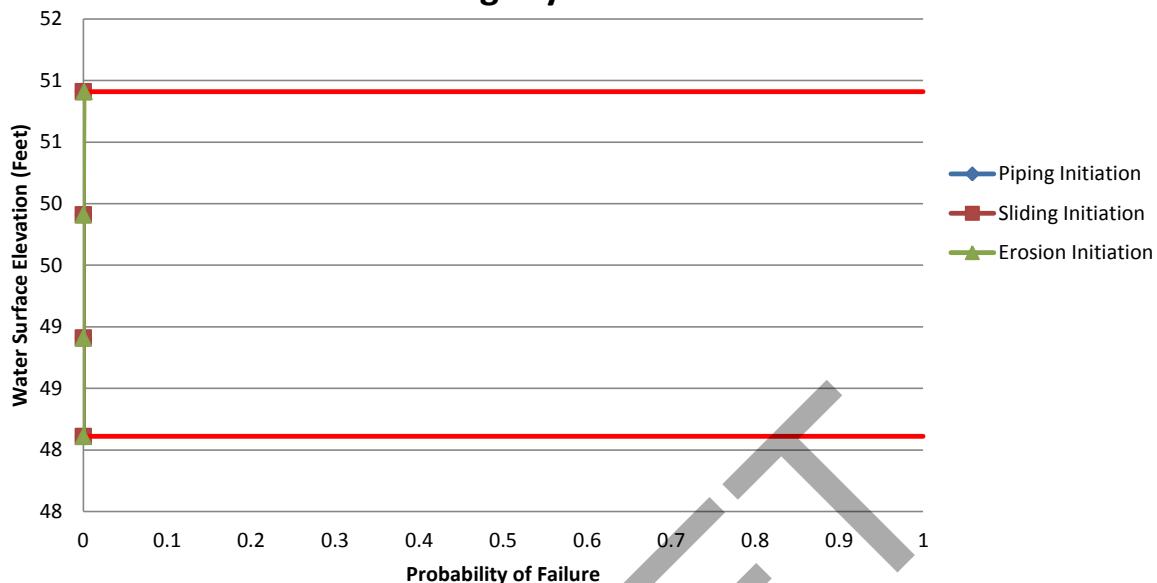
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

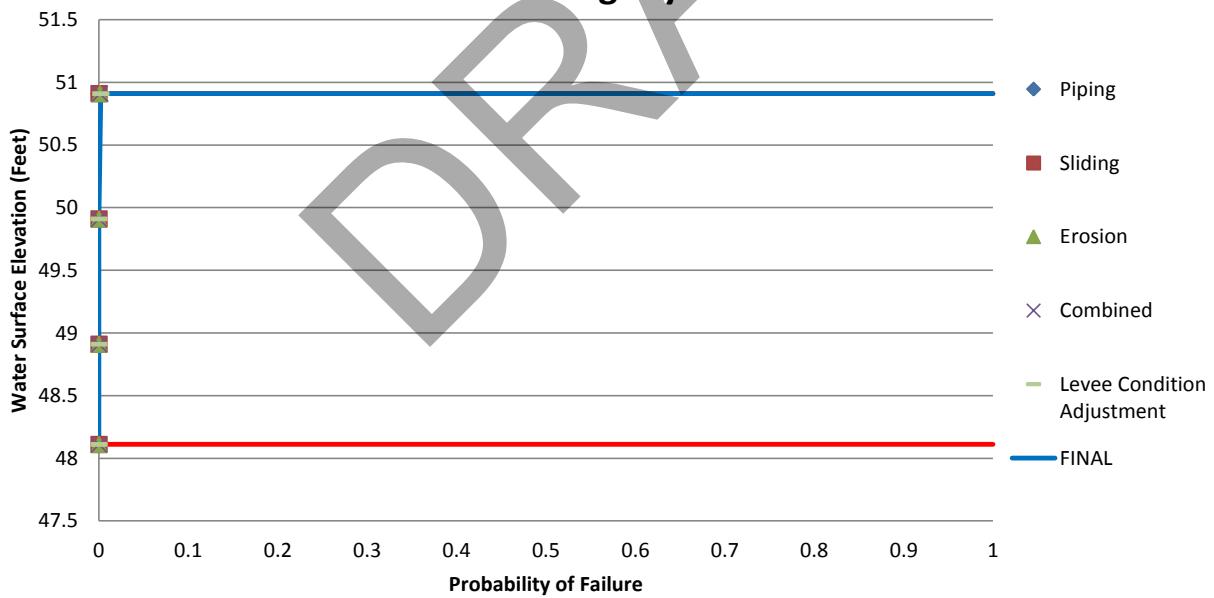
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



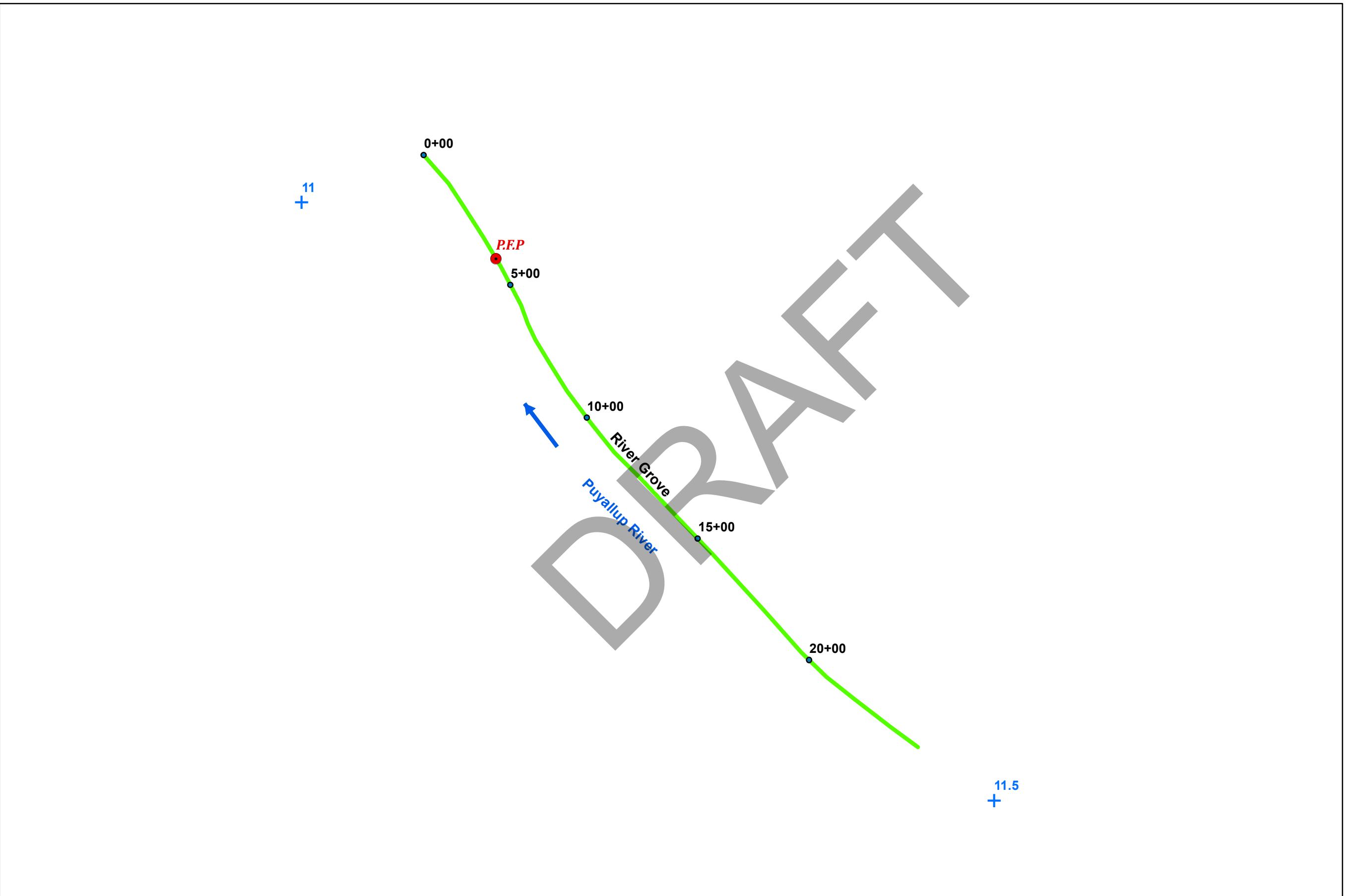
*Remarks: Fragility curve above displays the fragility curve at initiation only. No adjustments.*

### Levee Fragility Curve



*Remarks: The final levee fragility curve for the River Grove levee was based on engineering judgement for the piping and sliding failure modes. The levee prism is short, only 2.8 feet in height, and a failure prior to overtopping would not likely occur because the loading interval would be brief. Levee scour analysis was performed and the results are reflected in this fragility curve. Unacceptable levee condition was found to increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.*

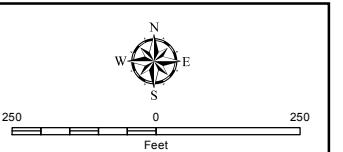
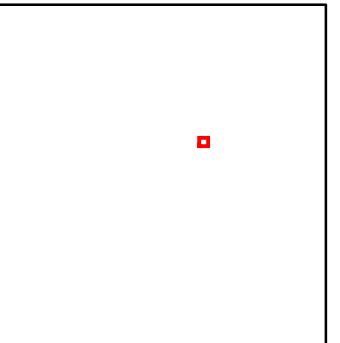
# River Grove Levee - Puyallup River



## Legend

- Potential Failure Point
- 2011 USACE Boring
- H&H Levee Breach Locations
- Levee Station
- Levee Centerline
- River Mileposts

## Location Map



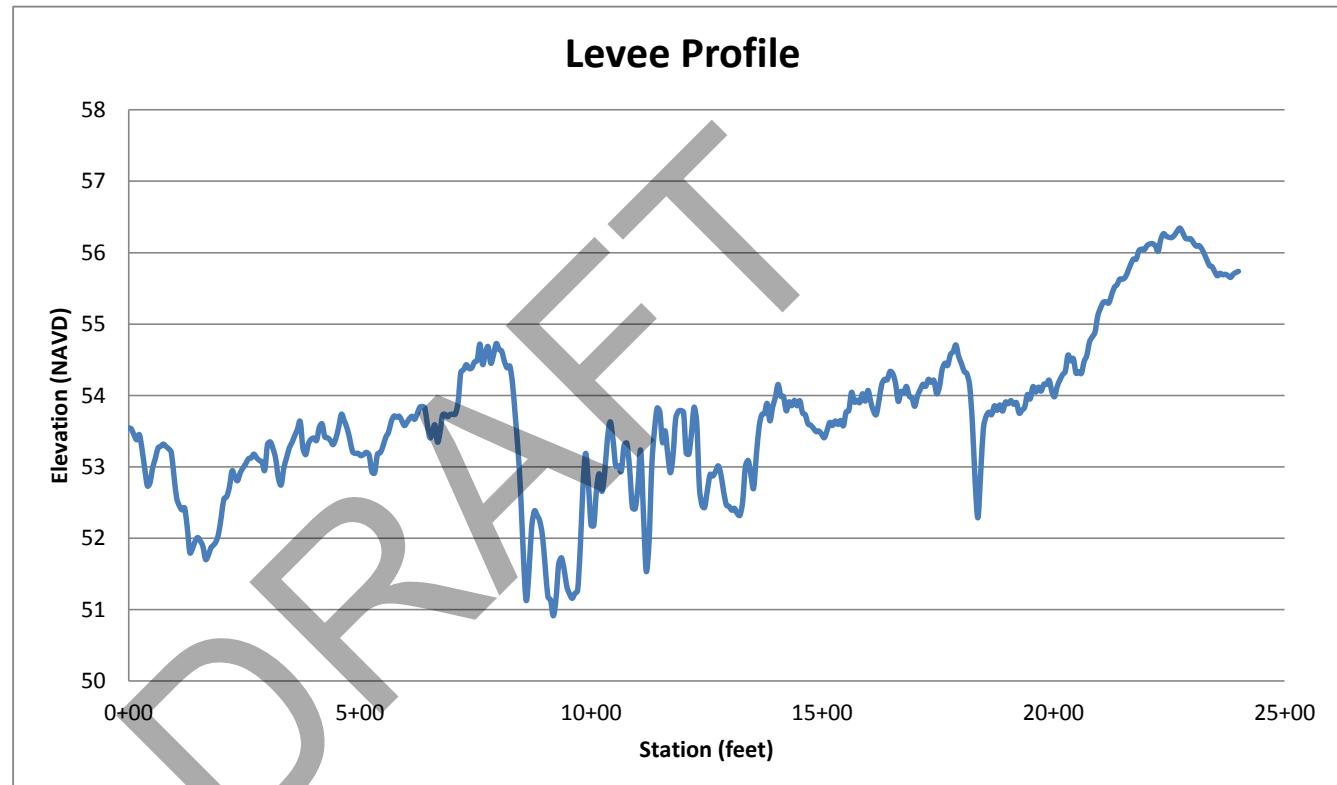
**DISCLAIMER:** While the United States Army Corps of Engineers, (hereinafter referred to as USACE) has made a reasonable effort to insure the accuracy of the maps and associated data, it should be explicitly noted that USACE makes no warranty, representation or guarantee, expressed or implied, as to the absolute accuracy, timeliness or completeness of any of the data provided herein. The USACE, its officers, agents, employees, or servants shall assume no liability of any nature for any errors, omissions, or inaccuracies in the information provided regardless of how caused. The USACE, its officers, agents, employees or servants shall assume no liability of any nature for any damages, losses, or expenses incurred by the user of the maps and associated data in reliance upon any information or data furnished here. By using these maps and associated data the user does so entirely at their own risk and explicitly acknowledges that he/she is aware of and agrees to be bound by this disclaimer and agrees not to present any claim or demands of any nature against the USACE, its officers, agents, employees, or servants, in any forum whatsoever for any damages of any nature whatsoever that may result from or may be caused in any way by the use of the maps and associated data.

**River Grove**

**Puyallup River**

<b>Min</b>	50.92
<b>Max</b>	56.35

<b>Station Begin</b>	0+00
<b>Station End</b>	24+00



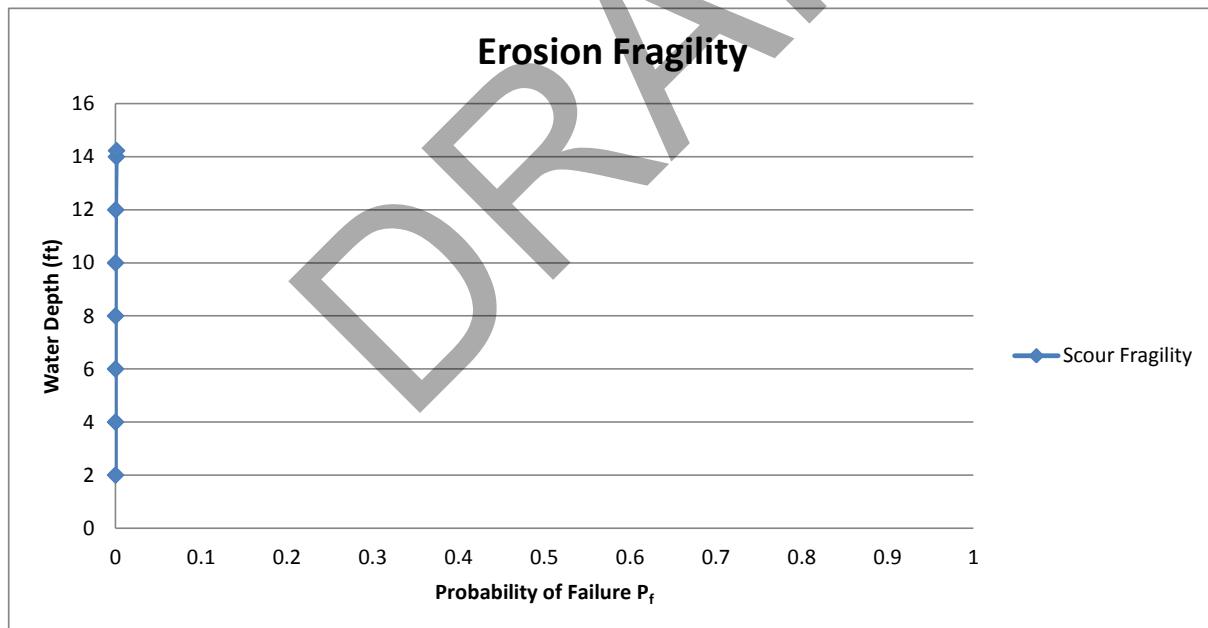
\*Profile elevations from a digital elevation model (DEM).

## Surface Erosion Analysis

### River Grove Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0009	CV(s) =	0.1	0.00009
Manning's "n"	n =	0.04	CV(n) =	0.15	0.006
Scouring Velocity		V <sub>crit</sub> =	14.23		2.85
CV(v <sub>crit</sub> )		0.2		0.2	

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	1.769	0.1581139		-2.084601584	0.254950976	-8.17648	1.4613E-16
4	2.808	0.1581139		-1.622503463	0.254950976	-6.36398	9.8294E-11
6	3.680	0.1581139		-1.352193391	0.254950976	-5.30374	5.6727E-08
8	4.458	0.1581139		-1.160405343	0.254950976	-4.55148	2.6634E-06
10	5.173	0.1581139		-1.011642975	0.254950976	-3.96799	3.6241E-05
12	5.842	0.1581139		-0.890095271	0.254950976	-3.49124	0.00024039
14	6.474	0.1581139		-0.787328151	0.254950976	-3.08816	0.00100702
14.23	6.545	0.1581139		-0.776464763	0.254950976	-3.04555	0.00116129



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

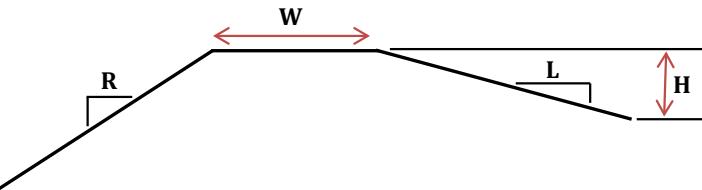
<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	River Road
<b>Station:</b>	138+72

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is minimally acceptable per USACE guidance. Erosion probability doubled due to ageing concrete panels.

#### Levee Geometry



Crown Width (W)	75 Feet
Landward Levee Height (H)	8 Feet
Riverward Slope (R)	1.6 H:1V
Landward Slope (L)	4.1 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	8 Feet
Breach Width at Top of Levee	179 Feet*
Breach Side Slope	2V:1H
Time to Full Development	2.56 Hours*

\*SERRI Report 70015-001

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation material is a poorly graded SAND with gravel (SP).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
	Loose / Soft	Low
X	Medium	X Medium
	Dense / Stiff	High

**Remarks:** Levee embankment material is a silty GRAVEL with sand (GM).

#### Duration Trigger

5 Days\*

\*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
31.82	1.00
31.81	0.36
29.82	0.29
27.82	0.21
23.82	0.08

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
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**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

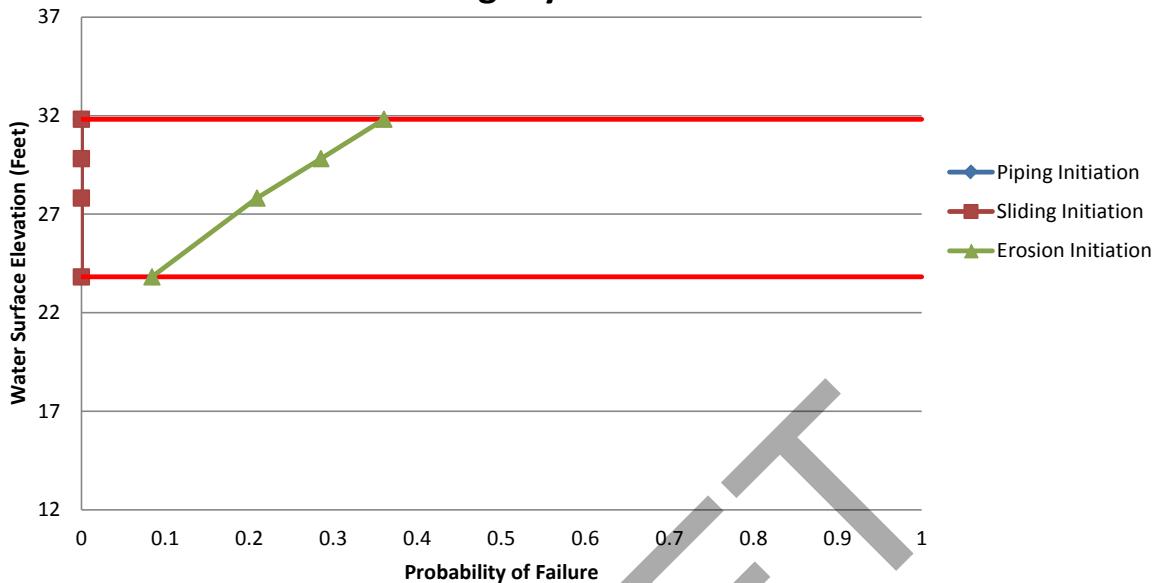
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

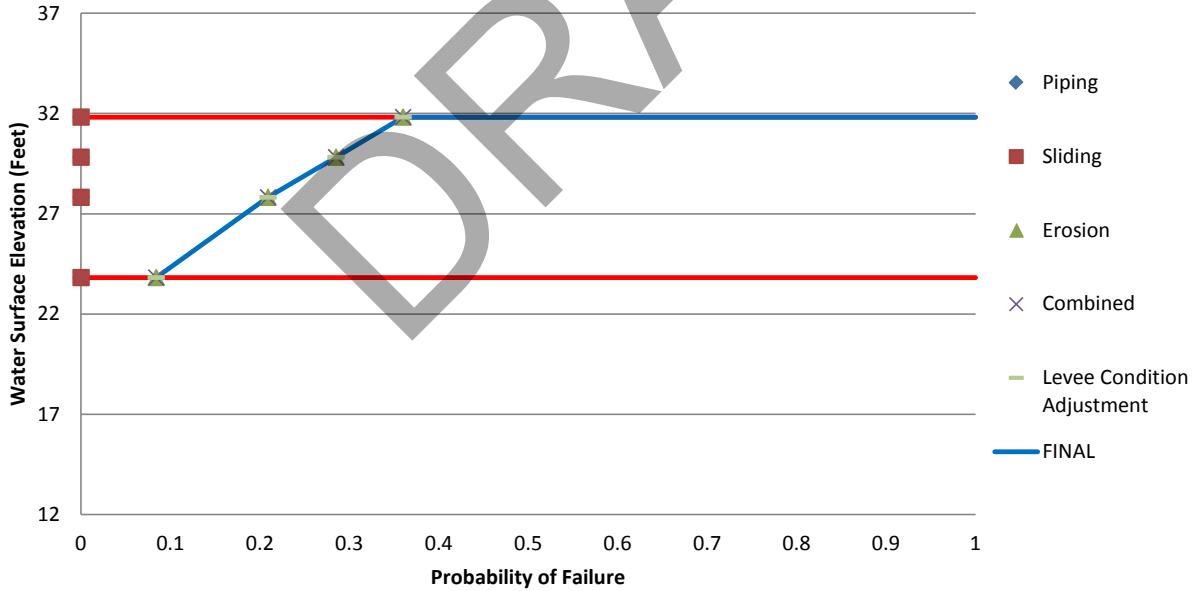
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



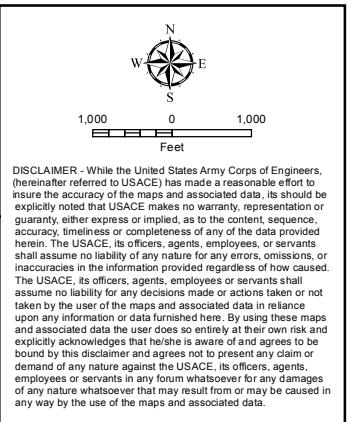
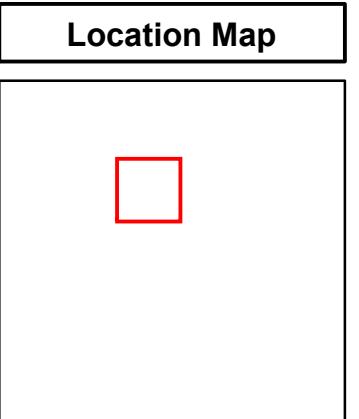
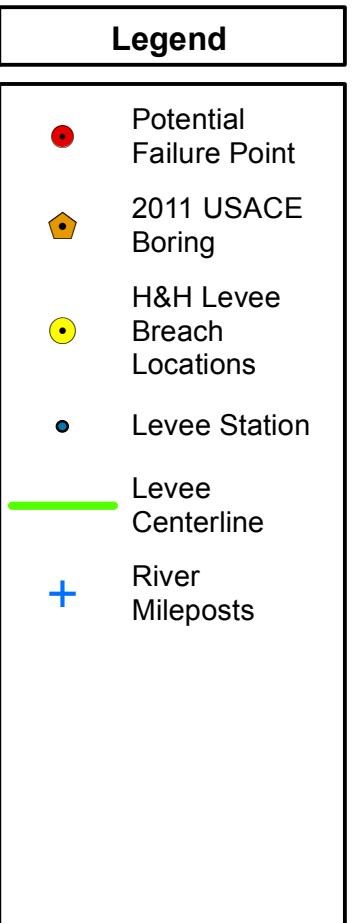
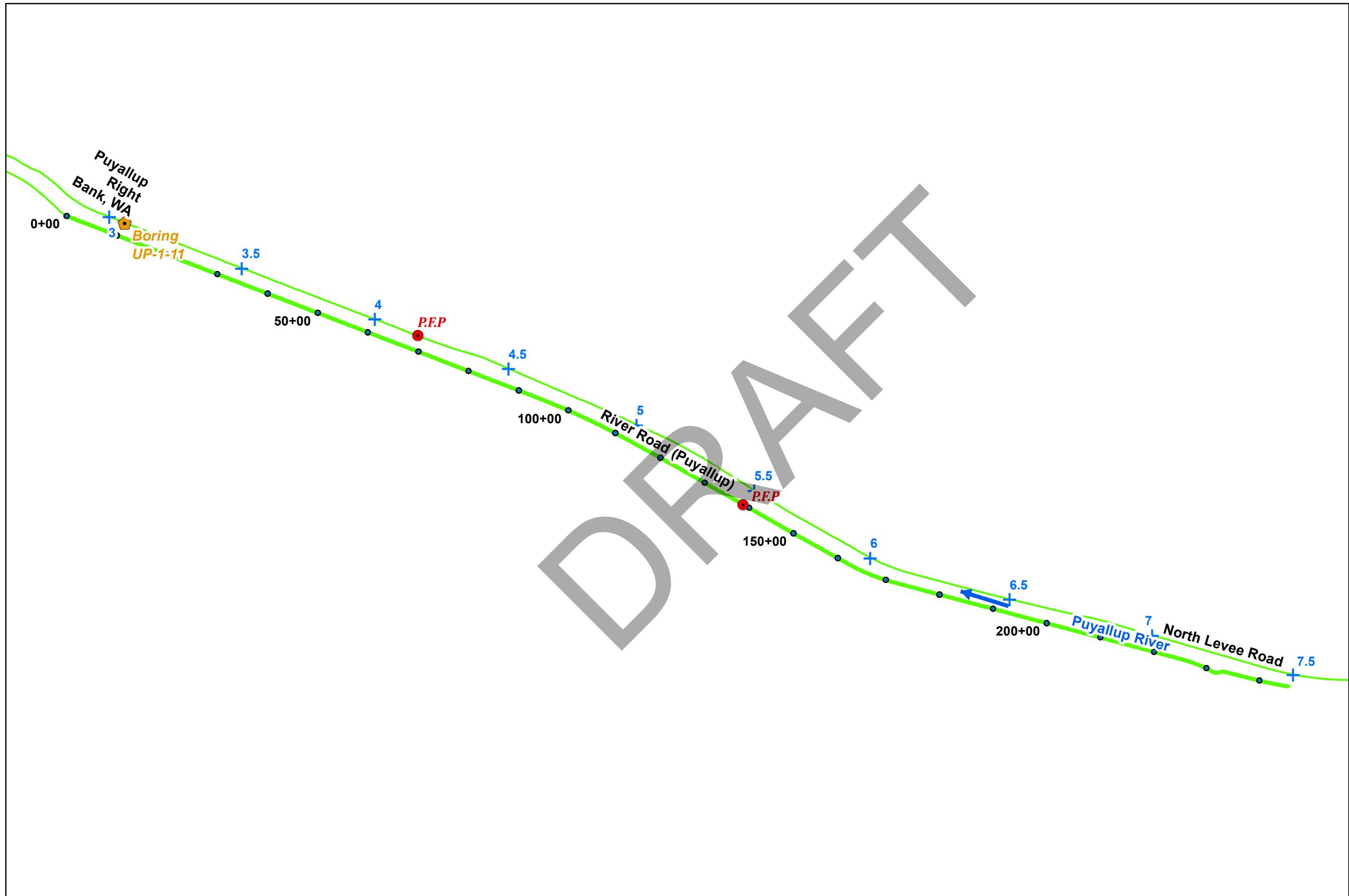
*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the River Road Levee is only accounting unique erosion computational values for probability of failure. Engineering judgment was used based on the geometry of the levee prism to conclude probability of failure for sliding and piping are essentially zero.

# River Road Levee - Puyallup River



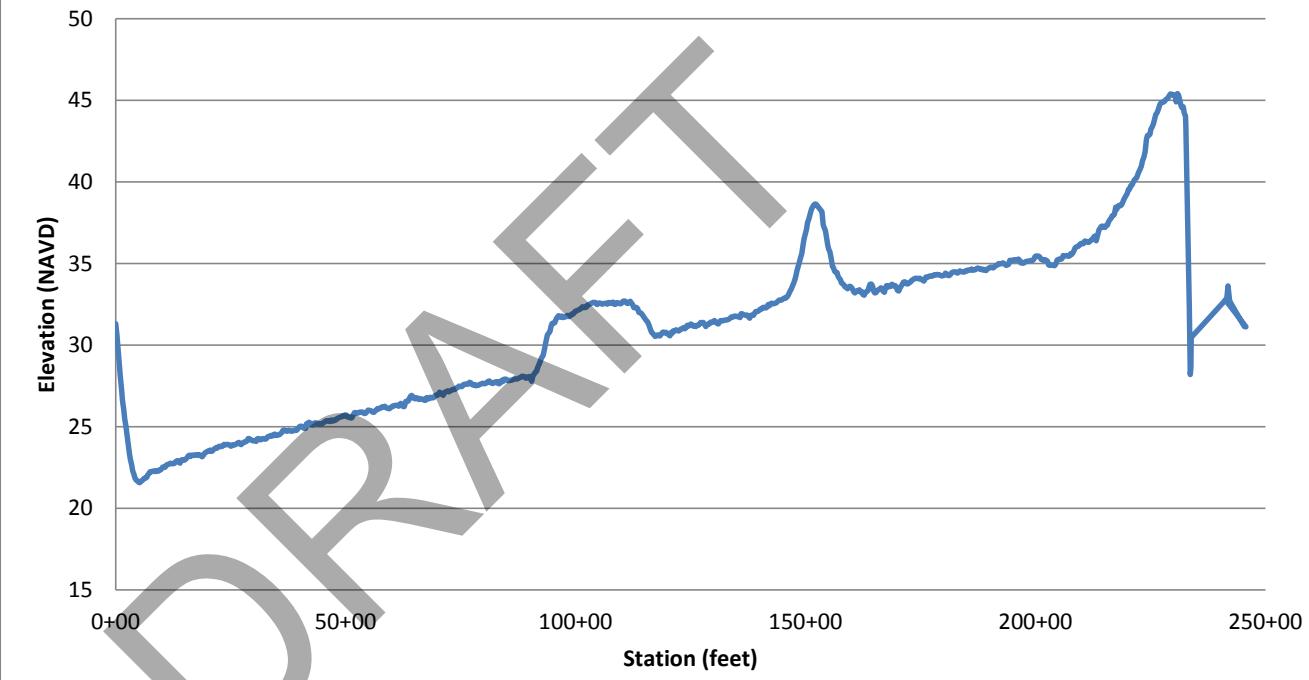
## River Road Levee

Puyallup River

<b>Min</b>	21.58
<b>Max</b>	45.42

<b>Station Begin</b>	0+00
<b>Station End</b>	241+63

### Levee Profile



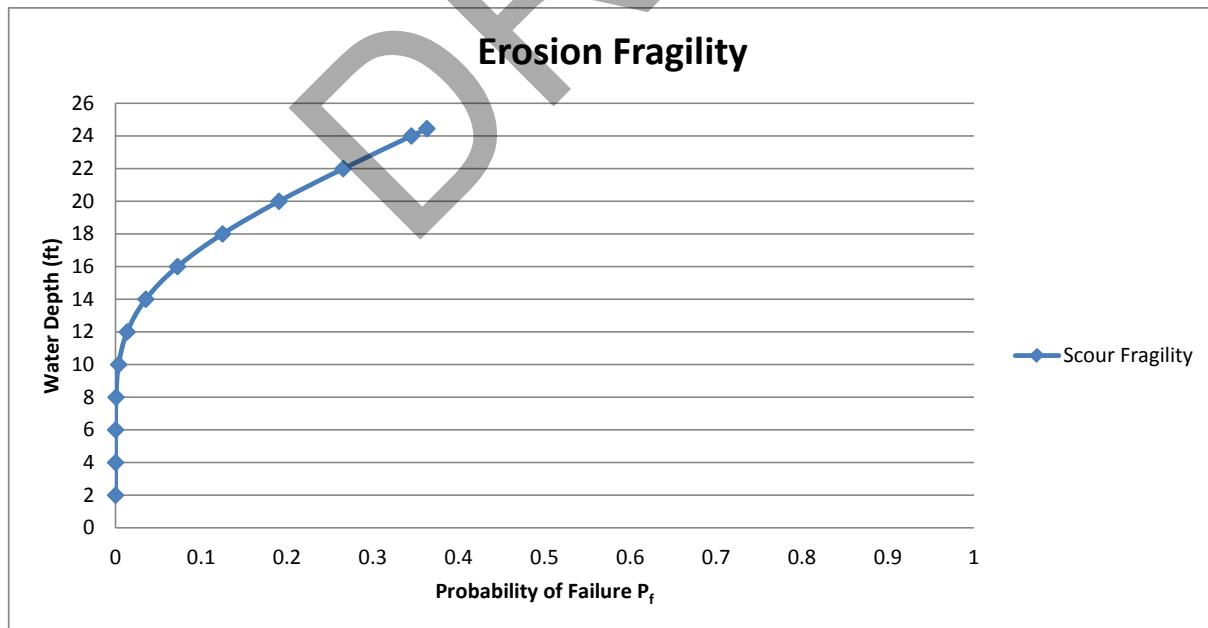
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### River Road Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.00062	CV(s) =	0.1	0.00062
Manning's "n"	n =	0.035	CV(n) =	0.15	0.00525
Scouring Velocity	$V_{crit} =$	9.74	$CV(V_{crit})$	0.2	1.95

Water Height (y)	E(v) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	1.678	0.1581139		-1.758564983	0.254950976	-6.89766	2.6433E-12
4	2.664	0.1581139		-1.296466863	0.254950976	-5.08516	1.8366E-07
6	3.491	0.1581139		-1.02615679	0.254950976	-4.02492	2.8498E-05
8	4.229	0.1581139		-0.834368742	0.254950976	-3.27266	0.0005327
10	4.907	0.1581139		-0.685606375	0.254950976	-2.68917	0.0035815
12	5.541	0.1581139		-0.56405867	0.254950976	-2.21242	0.01346882
14	6.141	0.1581139		-0.46129155	0.254950976	-1.80933	0.03519954
16	6.713	0.1581139		-0.372270622	0.254950976	-1.46017	0.0721223
18	7.261	0.1581139		-0.293748598	0.254950976	-1.15218	0.12462422
20	7.789	0.1581139		-0.223508254	0.254950976	-0.87667	0.19033255
22	8.300	0.1581139		-0.159968134	0.254950976	-0.62745	0.26518325
24	8.796	0.1581139		-0.10196055	0.254950976	-0.39992	0.34460692
24.45	8.906	0.1581139		-0.089576293	0.254950976	-0.35135	0.36266397



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Engineering Judgment & Erosion Analysis

#### General Information

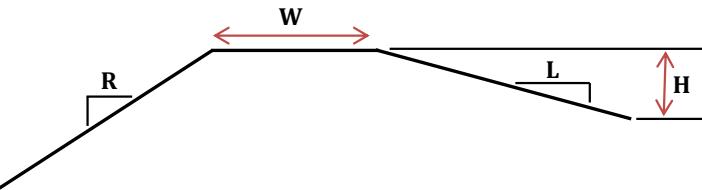
Location:	Pierce County, Washington
River:	Puyallup River
Levee Segment Name:	Riverside
Station:	5+00

#### Levee Condition Factor

Levee Condition Factor	2
------------------------	---

**Remarks:** Levee is deemed a 2 because the levee is rated unacceptable per USACE guidance. Extensive vegetation maintenance issues were noted.

#### Levee Geometry



Crown Width (W)	14 Feet
Landward Levee Height (H)	2 Feet
Riverward Slope (R)	2 H:1V
Landward Slope (L)	5 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	2 Feet
Breach Width at Top of Levee	44.8 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.39 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

Homogeneous Foundation
Interbedded Foundation
Layered Foundation

**Remarks:** Levee foundation material is unknown.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
Loose / Soft		Low
Medium		Medium
Dense / Stiff		High

**Remarks:** Levee embankment material is unknown.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

#### Final Fragility Curve

Elev.	Prob.
57.21	1.00
57.21	0.66
56.21	0.58
55.21	0.50
55.21	0.00

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

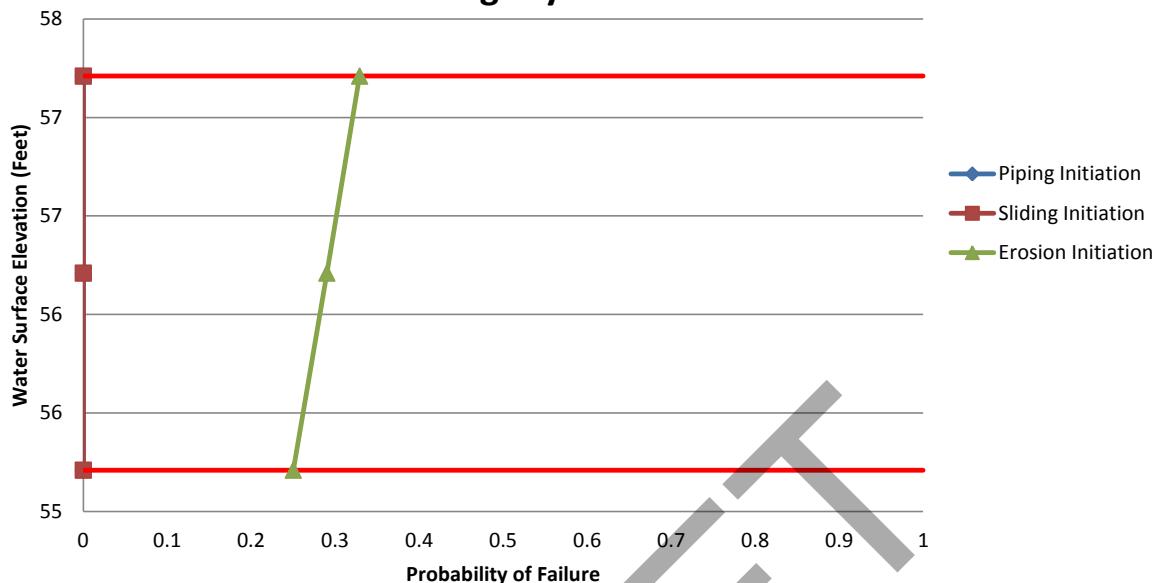
Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

# PUYALLUP BASIN GENERAL INVESTIGATION

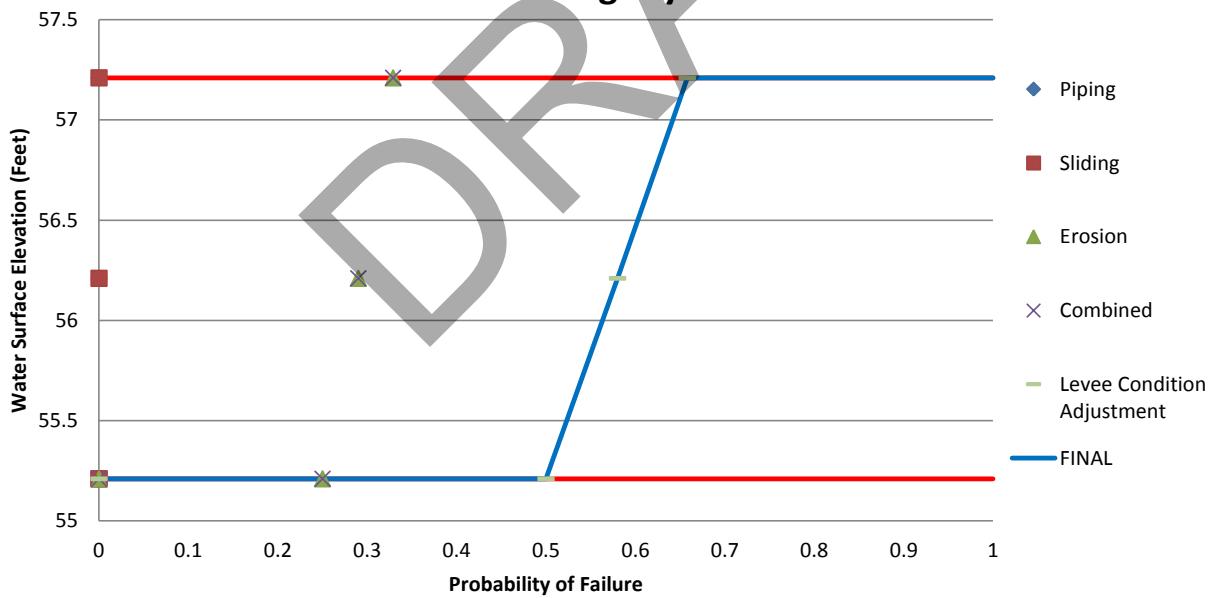
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



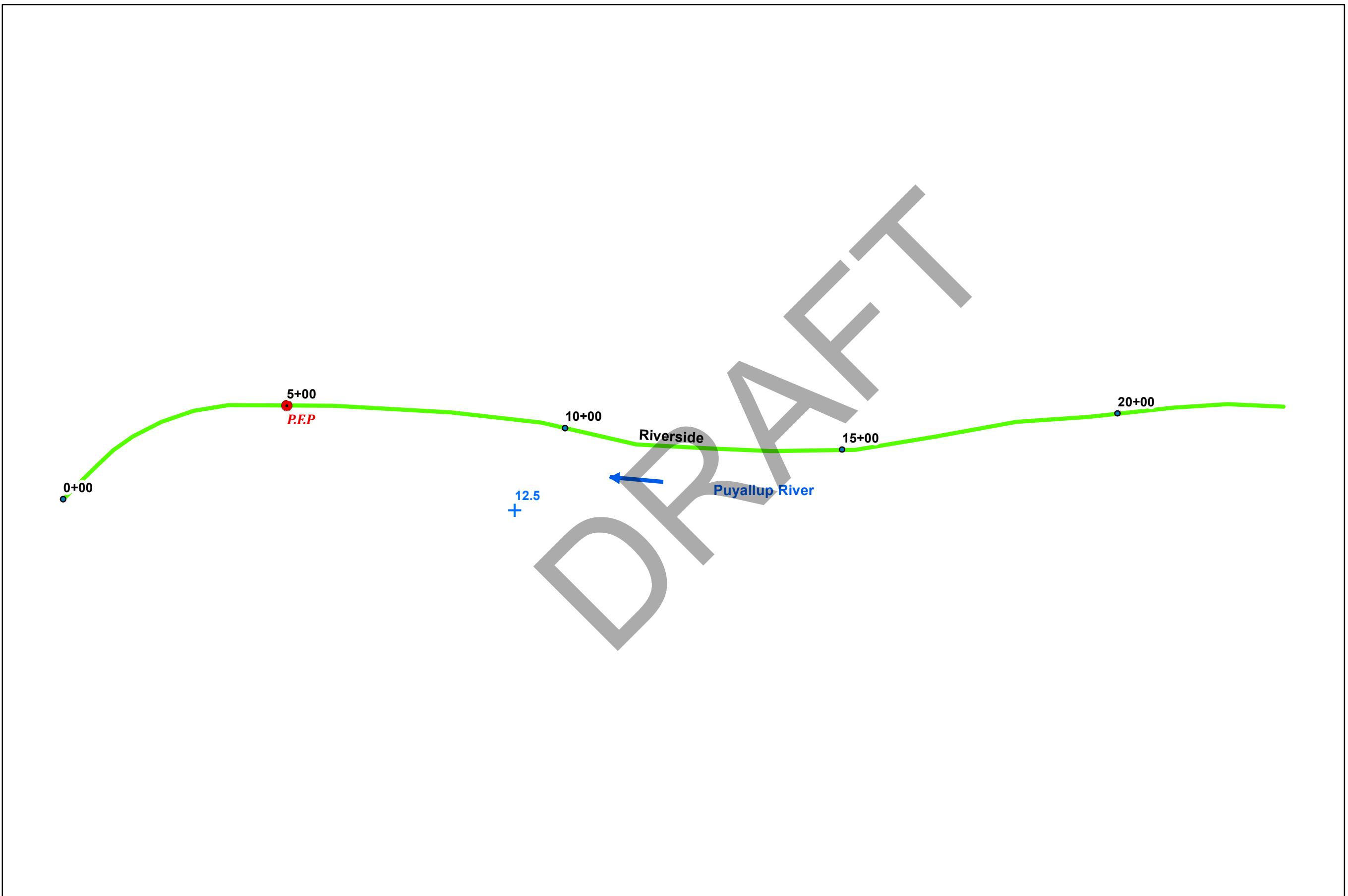
*Remarks: Fragility curve above displays the fragility curve at initiation only. No adjustments.*

### Levee Fragility Curve



*Remarks: The final levee fragility curve for the Riverside levee was based on engineering judgement for the piping and sliding failure modes. The levee prism is short, only 2 feet in height, and a failure prior to overtopping would not likely occur because the loading interval would be brief. Levee scour analysis was performed and the results are reflected in this fragility curve. Unacceptable levee condition was found to increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.*

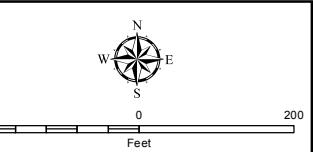
# Riverside Levee - Puyallup River



## Legend

- Potential Failure Point
- 2011 USACE Boring
- H&H Levee Breach Locations
- Levee Station
- Levee Centerline
- River Mileposts

## Location Map

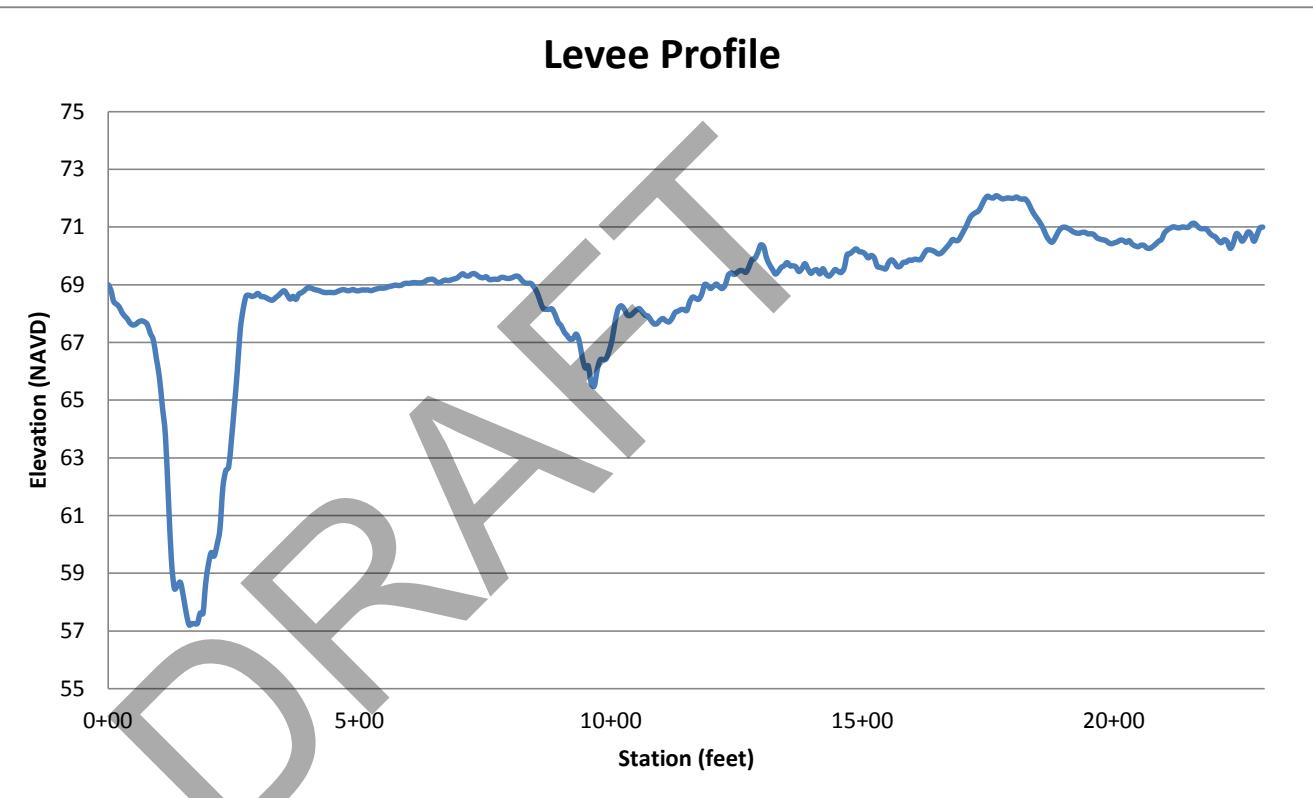


**DISCLAIMER:** While the United States Army Corps of Engineers, (hereinafter referred to as USACE) has made a reasonable effort to insure the accuracy of the maps and associated data, it should be explicitly noted that USACE makes no warranty, representation or guarantee, expressed or implied, as to the absolute accuracy, timeliness or completeness of any of the data provided herein. The USACE, its officers, agents, employees, or servants shall assume no liability of any nature for any errors, omissions, or inaccuracies in the information provided regardless of how caused. The USACE, its officers, agents, employees or servants shall assume no liability of any nature for any damages, losses, or expenses not taken by the user of the maps and associated data in reliance upon any information or data furnished here. By using these maps and associated data the user does so entirely at their own risk and bound by this disclaimer and agrees not to present any claim or demands of any nature against the USACE, its officers, agents, employees, or servants, in any forum whatsoever for any damages of any nature whatsoever that may result from or may be caused in any way by the use of the maps and associated data.

*Riverside*  
*Puyallup River*

<i>Min</i>	57.21
<i>Max</i>	72.09

<i>Station Begin</i>	0+00
<i>Station End</i>	22+96



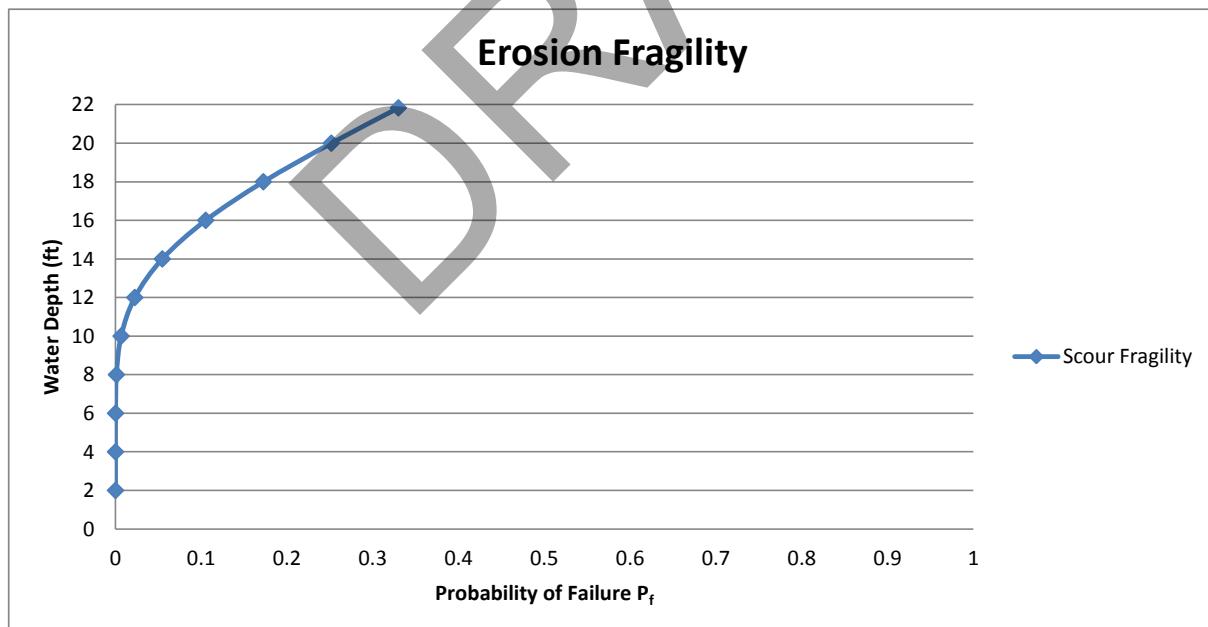
\*Profile elevations from a digital elevation model (DEM).

## Surface Erosion Analysis

### Riverside Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0018	CV(s) =	0.1	0.00018
Manning's "n"	n =	0.04	CV(n) =	0.15	0.006
Scouring Velocity		V <sub>crit</sub> =	13.77		2.75
CV(v <sub>crit</sub> )			0.2		

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
2	2.502	0.1581139		-1.705758733	0.254950976	-6.69054	1.1118E-11
4	3.972	0.1581139		-1.243660612	0.254950976	-4.87804	5.3573E-07
6	5.204	0.1581139		-0.97335054	0.254950976	-3.81779	6.7325E-05
8	6.305	0.1581139		-0.781562492	0.254950976	-3.06554	0.00108639
10	7.316	0.1581139		-0.632800125	0.254950976	-2.48205	0.00653152
12	8.261	0.1581139		-0.51125242	0.254950976	-2.0053	0.02246565
14	9.155	0.1581139		-0.4084853	0.254950976	-1.60221	0.05455446
16	10.008	0.1581139		-0.319464372	0.254950976	-1.25304	0.10509515
18	10.825	0.1581139		-0.240942348	0.254950976	-0.94505	0.17231575
20	11.613	0.1581139		-0.170702004	0.254950976	-0.66955	0.25157288
21.83	12.311	0.1581139		-0.112333406	0.254950976	-0.44061	0.32974845



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Sportsmen Cross Section Model & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Puyallup River
<b>Levee Segment Name:</b>	Sportsmen
<b>Station:</b>	27+00

#### Levee Condition Factor

Levee Condition Factor	2
------------------------	---

**Remarks:** Levee is deemed a 2 because the levee is unacceptable per USACE guidance. Vegetation maintenance issues, missing flappgates, and obstructions were noted.

#### Levee Geometry

Crown Width (W)	10 Feet
Landward Levee Height (H)	4 Feet
Riverward Slope (R)	1.75 H:1V
Landward Slope (L)	2 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	4 Feet
Breach Width at Top of Levee	89.6 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.78 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is a medium dense silty SAND (SM).

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )
	Loose / Soft	Low
X	Medium	X Medium
	Dense / Stiff	High

**Remarks:** Levee embankment material is medium dense to dense silty GRAVEL with sand (GM).

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days\*

\*Expert Elicitation

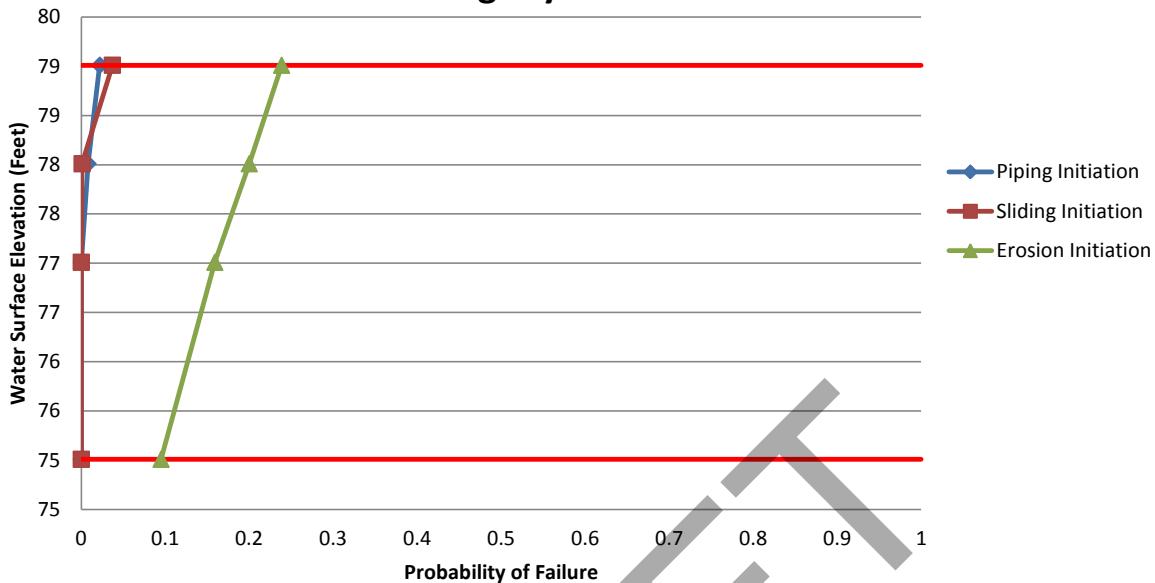
#### Final Fragility Curve

Elev.	Prob.
79.01	1.00
79.01	0.53
78.01	0.40
77.01	0.32
75.01	0.19

# PUYALLUP BASIN GENERAL INVESTIGATION

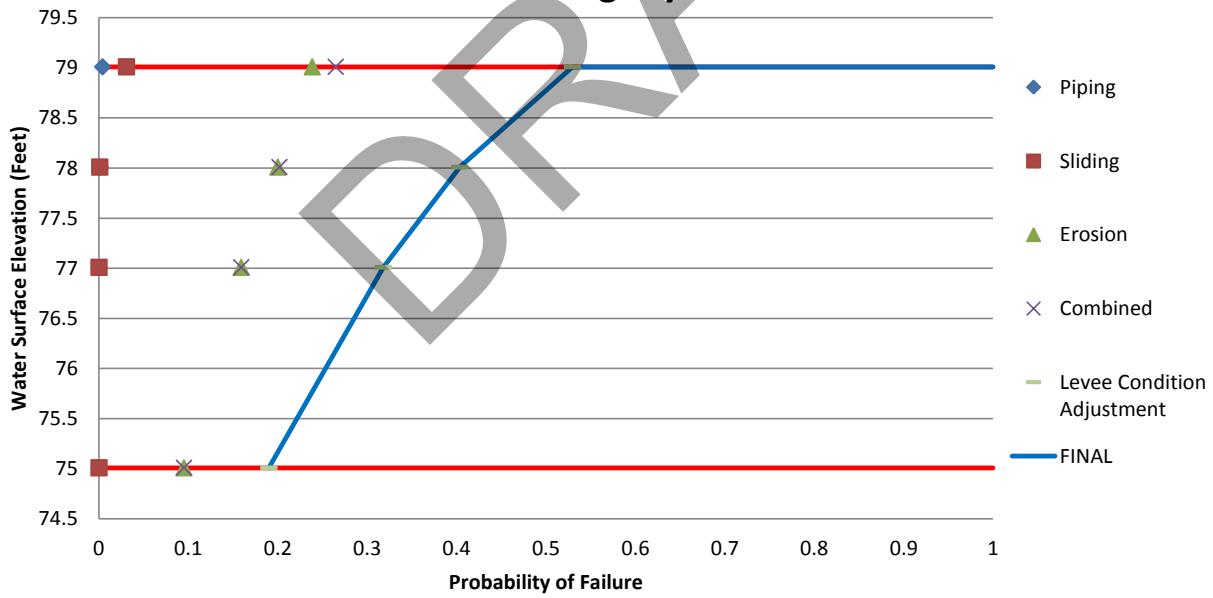
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks: Fragility curve above displays the fragility curve at initiation only. No adjustments.*

### Levee Fragility Curve



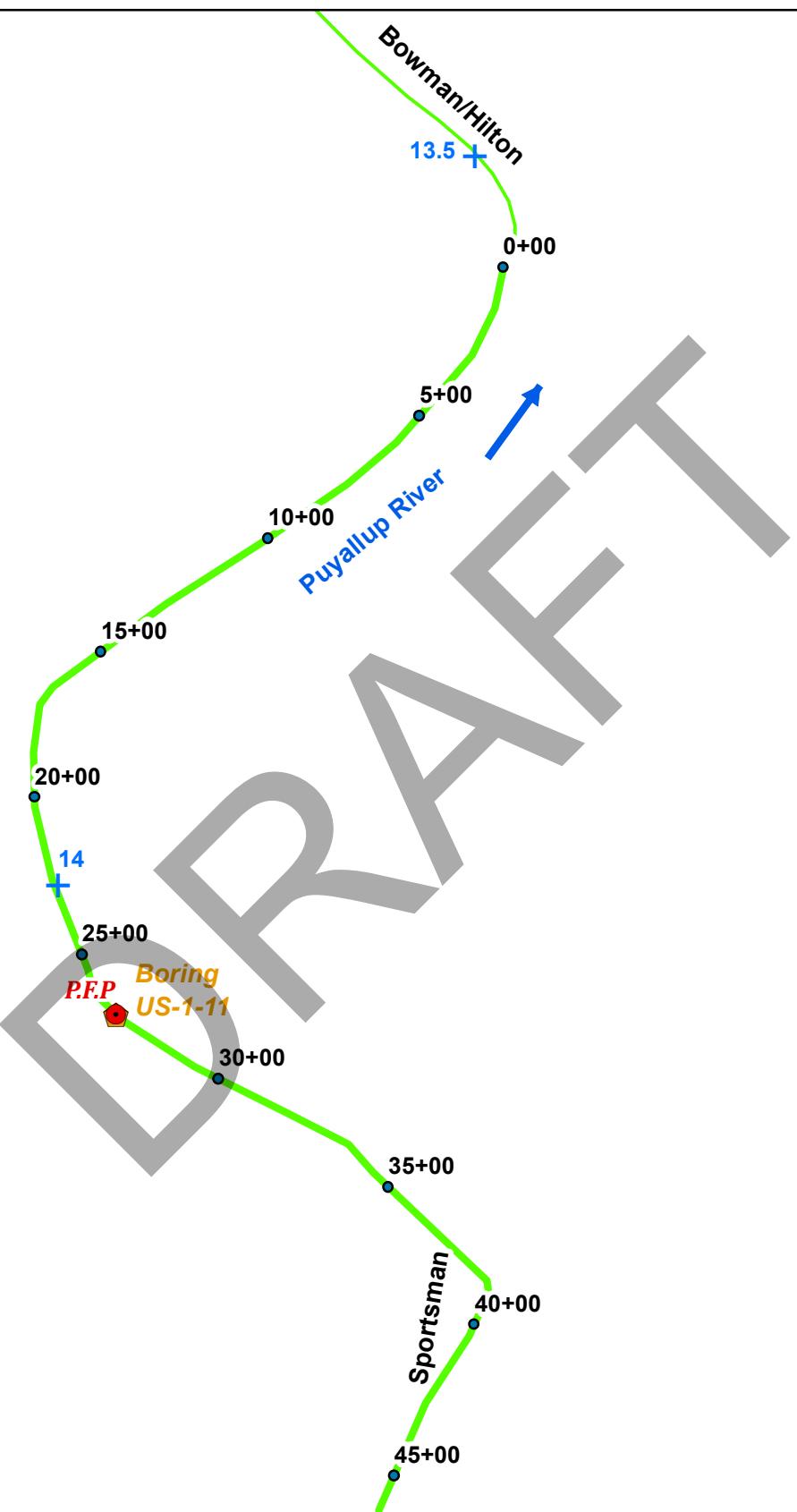
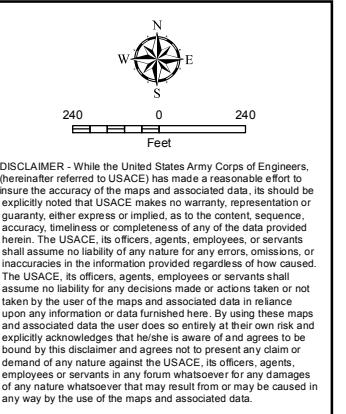
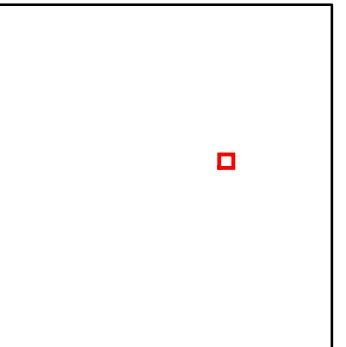
*Remarks: The final levee fragility curve for the Sportsmen Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Unacceptable levee condition was found to increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.*

# Sportsman Levee - Puyallup River

## Legend

- Potential Failure Point
- 2011 USACE Boring
- H&H Levee Breach Locations
- Levee Station
- Levee Centerline
- River Mileposts

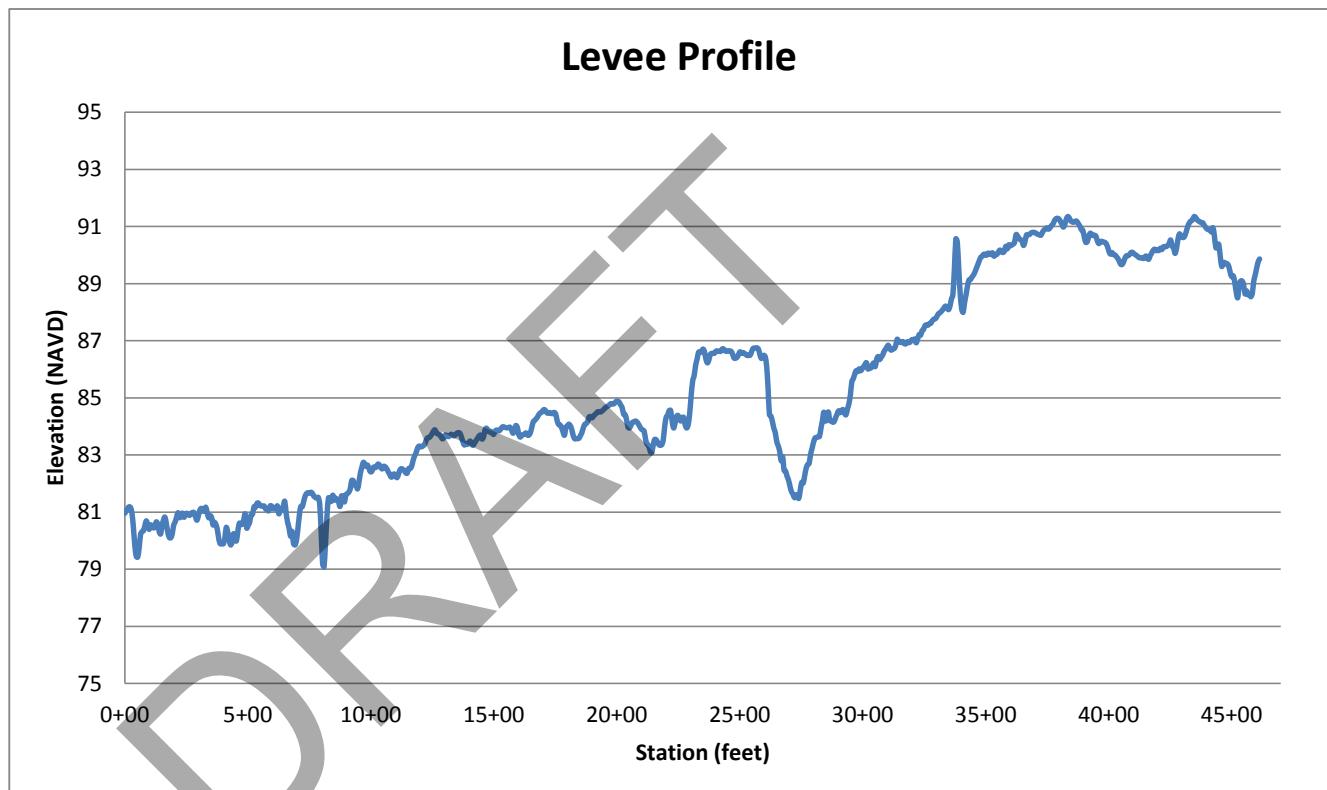
## Location Map



**Sportsmen**  
**Puyallup River**

<b>Min</b>	79.08
<b>Max</b>	91.35

<b>Station Begin</b>	0+00
<b>Station End</b>	46+13



\*Profile elevations from a digital elevation model (DEM).

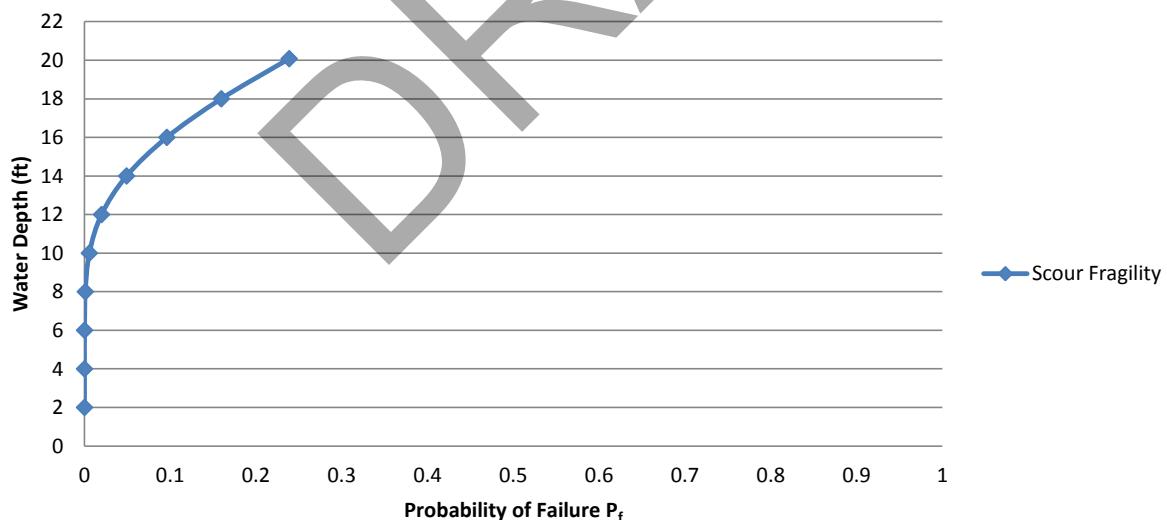
## Surface Erosion Analysis

### Sportsmen Levee

	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.00187	CV(s) =	0.1	0.000187
Manning's "n"	n =	0.04	CV(n) =	0.15	0.006
Scouring Velocity	$V_{crit} =$	14.23	$CV(V_{crit})$	0.2	2.85

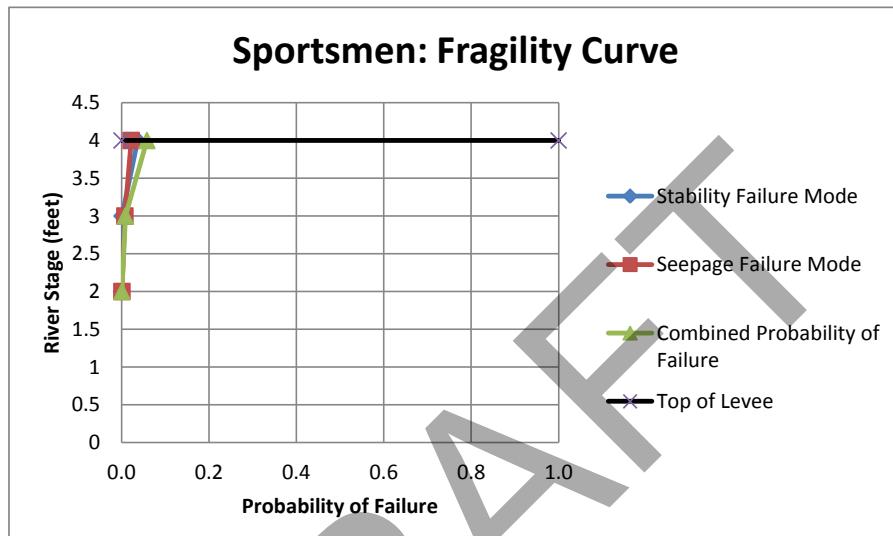
Water Height (y)	E(V) (ft/sec)	CV(v)		$\ln(E(v)/E(V_{crit}))$	$\sqrt{CV_{crit}^2 + CV^2}$	$\beta$	$P_f$
0	0.000	0.1581139					
2	2.550	0.1581139		-1.71895211	0.254950976	-6.74228	7.7957E-12
4	4.048	0.1581139		-1.25685399	0.254950976	-4.92979	4.116E-07
6	5.305	0.1581139		-0.986543918	0.254950976	-3.86954	5.452E-05
8	6.426	0.1581139		-0.79475587	0.254950976	-3.11729	0.00091261
10	7.457	0.1581139		-0.645993502	0.254950976	-2.53379	0.00564174
12	8.420	0.1581139		-0.524445798	0.254950976	-2.05705	0.01984092
14	9.332	0.1581139		-0.421678678	0.254950976	-1.65396	0.04906784
16	10.201	0.1581139		-0.332657749	0.254950976	-1.30479	0.09598201
18	11.034	0.1581139		-0.254135726	0.254950976	-0.9968	0.15943023
20.08	11.868	0.1581139		-0.181234034	0.254950976	-0.71086	0.238586

### Erosion Fragility



Sportsmen					
Fragility Curve					
Cross Section from STA 27+00					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 4' +					
4	0.037	4	0.022	4	0.058
3	0.001	3	0.008	3	0.009
2	2.0E-05	2	9.0E-04	2	0.001



OVERTOPPING - 4' +	
Top of Levee	
4	0
4	1

Stability	TOL		TOL -1'		TOL -2'		Seepage
	Stability	Seepage	Stability	Seepage	Stability	Seepage	
MLV	1.33	0.24	1.49	0.18	1.62	0.11	MLV
Soil Unit 1	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.33	0.24	1.48	0.18	1.61	0.11 γB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.35	0.24	1.49	0.18	1.62	0.11 γB +1SD
	log(K <sub>h</sub> )-1SD	1.48	0.25	1.58	0.18	1.66	0.11 (K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	1.45	0.24	1.63	0.18	1.83	0.11 (K <sub>h</sub> /K <sub>v</sub> )+1SD
	γ -1SD	1.32	0.21	1.48	0.15	1.63	0.10 (K <sub>h</sub> /K <sub>v</sub> )-1SD
	γ +1SD	1.34	0.27	1.49	0.20	1.61	0.13 (K <sub>h</sub> /K <sub>v</sub> )+1SD
	φ -1SD	1.24	0.18	1.39	0.14	1.55	0.09 log(K <sub>h</sub> )-1SD
	φ +1SD	1.43	0.28	1.60	0.22	1.69	0.15 log(K <sub>h</sub> )+1SD
Soil Unit 2	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.36	0.33	1.50	0.26	1.63	0.17 log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.32	0.13	1.48	0.09	1.60	0.06 log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	1.21	(i)	1.35	(i)	1.52	(i)
	log(K <sub>h</sub> )+1SD	1.55		1.63		1.70	
	γ -1SD	1.31	(i)	1.47	(i)	1.58	(i)
	γ +1SD	1.35		1.51		1.66	
	φ -1SD	1.28	(i)	1.43	(i)	1.51	(i)
	φ +1SD	1.39		1.55		1.74	

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Sportsmen
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Sportsmen cross section from STA 27+00. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-4	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-2.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0	3.81	
2	52.6	1.5	1.5	-4	-2.3	0	0	0	0	0	3.48	
3	62.6	1.5	1.5	-4	-2.3	0	0	0	0	0	4.14	0.66
4	57.6	1	1.5	-4	-2.3	0	0	0	0	0	3.72	
5	57.6	2	1.5	-4	-2.3	0	0	0	0	0	3.88	0.16129
6	57.6	1.5	1	-4	-2.3	0	0	0	0	0	4.37	
7	57.6	1.5	2	-4	-2.3	0	0	0	0	0	3.47	-0.90586
8	57.6	1.5	1.5	-5	-2.3	0	0	0	0	0	5.01	
9	57.6	1.5	1.5	-3	-2.3	0	0	0	0	0	3.26	-1.74639
10	57.6	1.5	1.5	-4	-3.3	0	0	0	0	0	2.80	
11	57.6	1.5	1.5	-4	-1.3	0	0	0	0	0	7.16	4.35843
12	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
13	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
14	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
15	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
16	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
17	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
18	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
19	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
20	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
21	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	2.415
Coefficient of variation of F,	$V_F$	0.634
Log normal reliability index,	$\beta_{LN}$	2.012
Reliability		0.978
Probability of failure		0.022

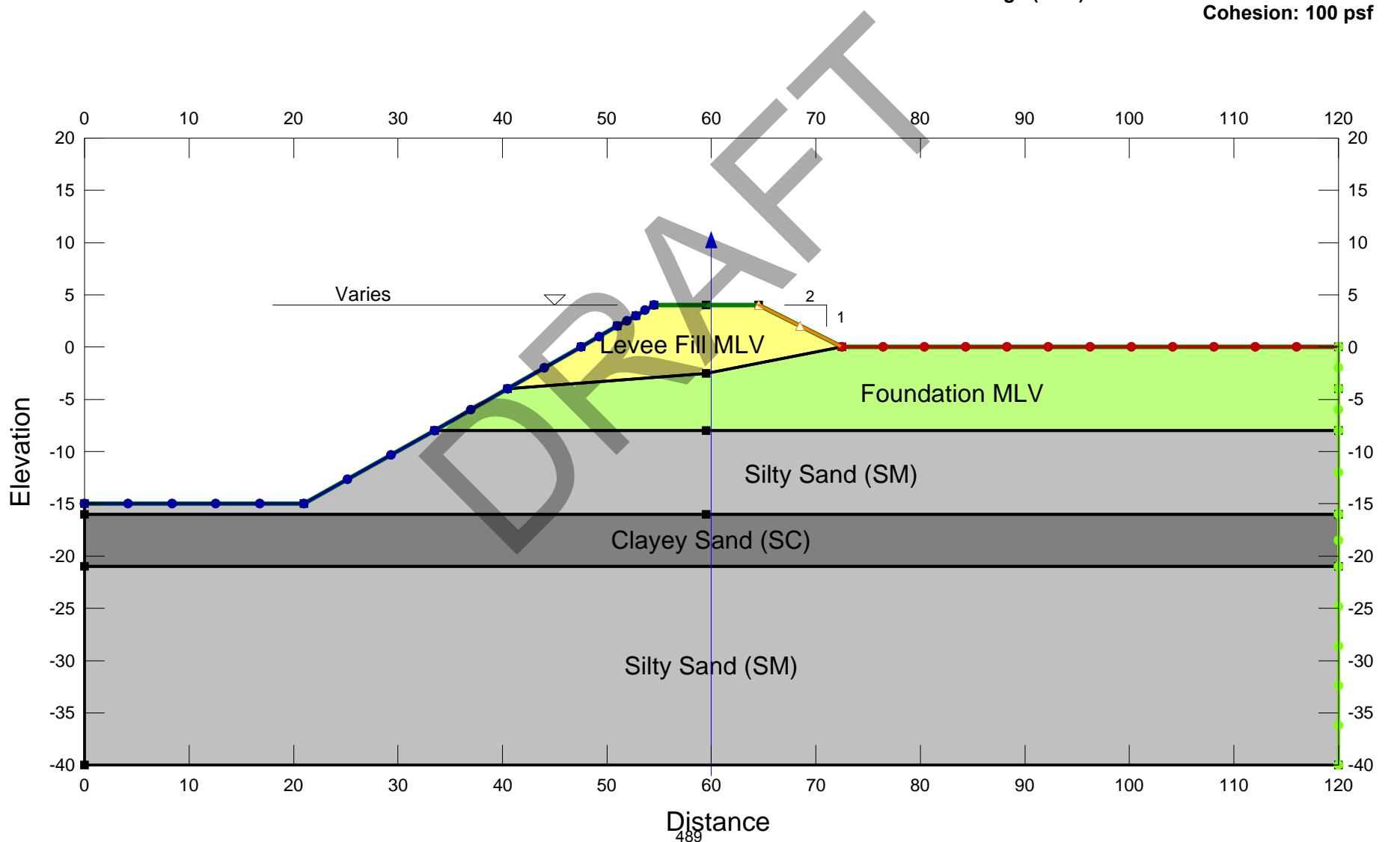
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



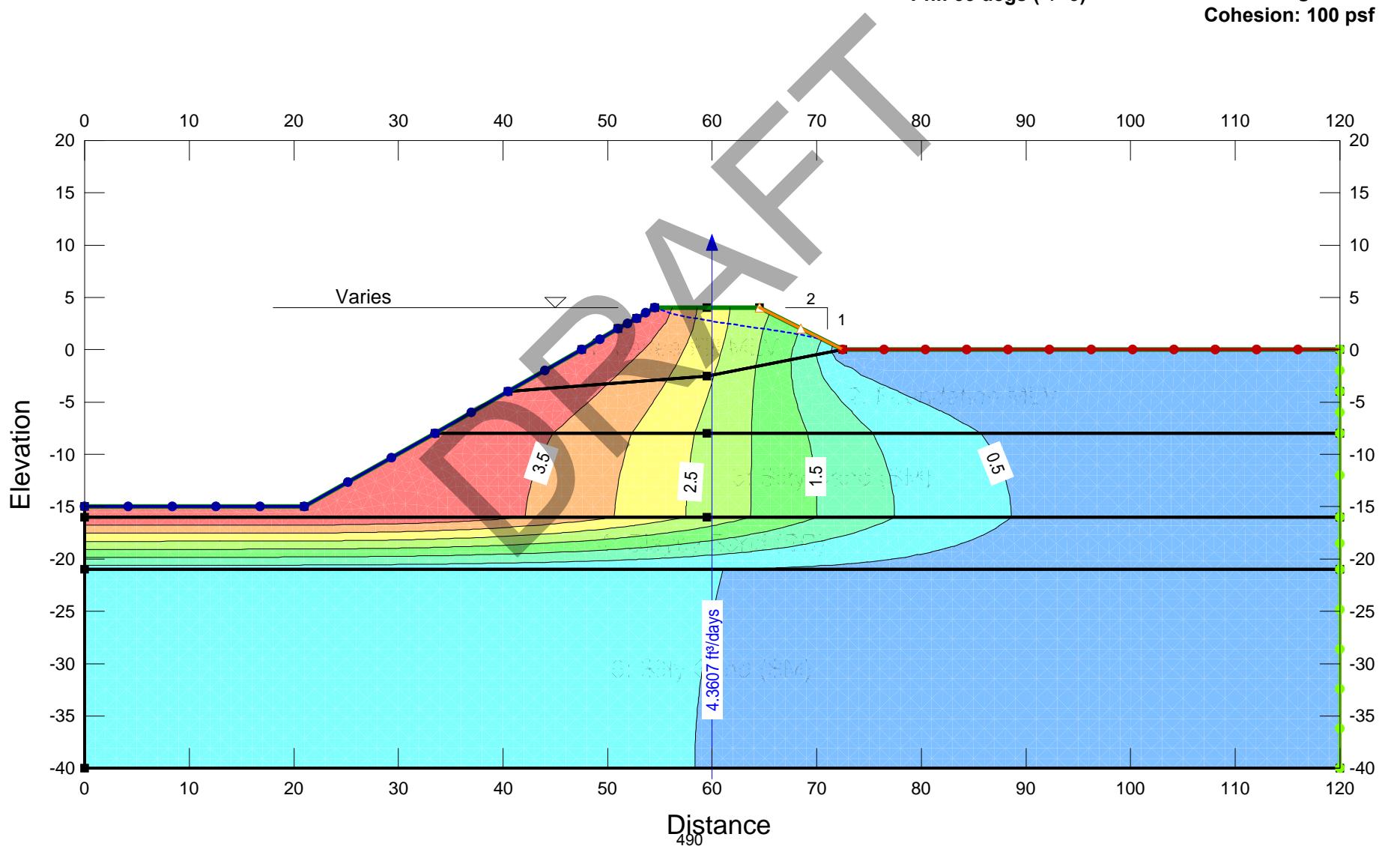
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



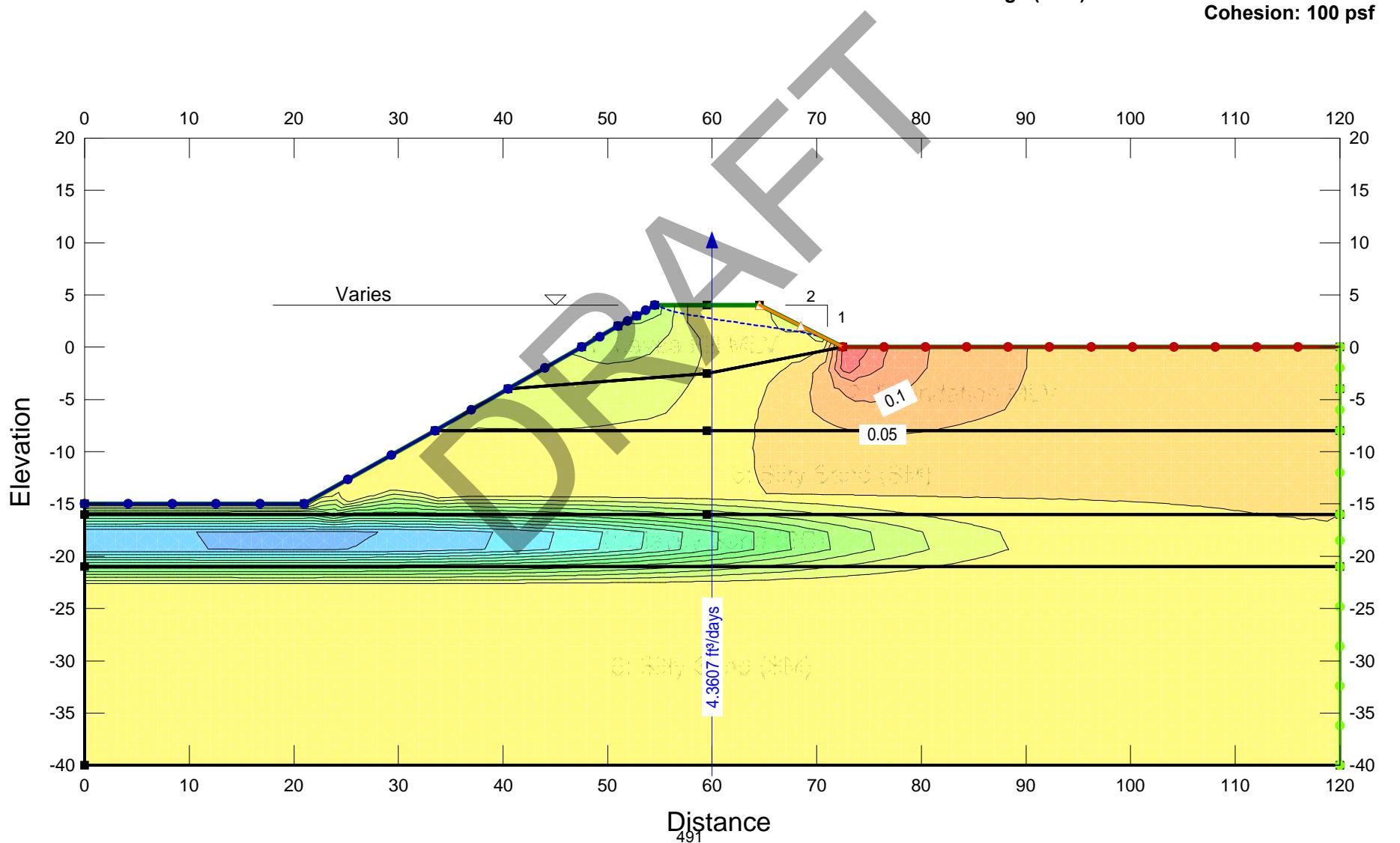
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



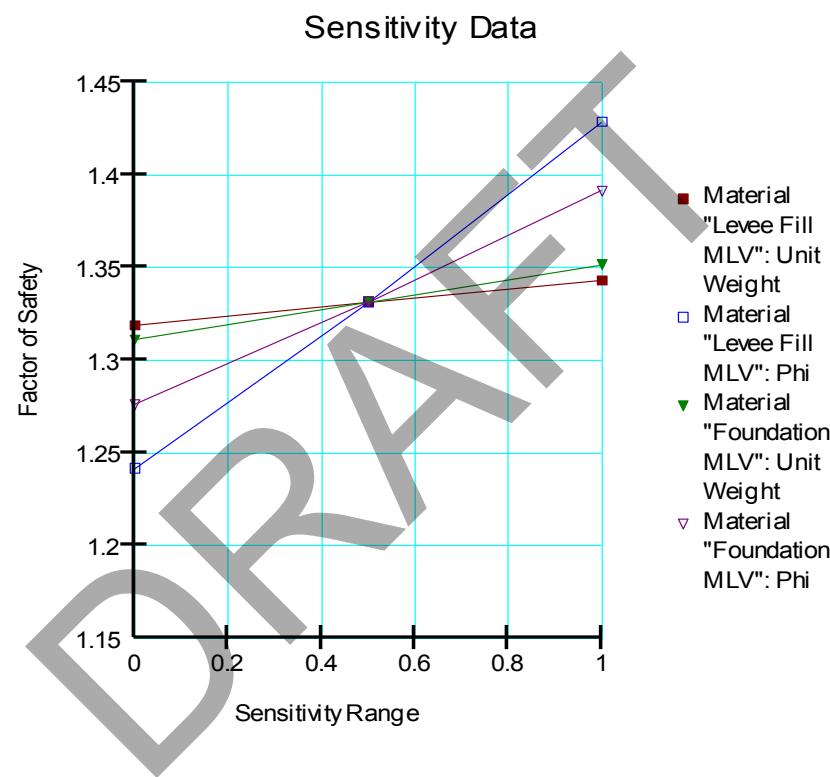
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Sportsmen
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Sportsmen cross section from STA 27+00. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-4	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	34	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-4	125	34	1.5	-2.3	120	33	0	0	1.33	
2	1	-4	125	34	1.5	-2.3	120	33	0	0	1.33	
3	2	-4	125	34	1.5	-2.3	120	33	0	0	1.35	0.02
4	1.5	-5	125	34	1.5	-2.3	120	33	0	0	1.48	
5	1.5	-3	125	34	1.5	-2.3	120	33	0	0	1.45	-0.03
6	1.5	-4	120	34	1.5	-2.3	120	33	0	0	1.32	
7	1.5	-4	130	34	1.5	-2.3	120	33	0	0	1.34	0.02431
8	1.5	-4	125	31	1.5	-2.3	120	33	0	0	1.24	
9	1.5	-4	125	37	1.5	-2.3	120	33	0	0	1.43	0.18687
10	1.5	-4	125	34	1	-2.3	120	33	0	0	1.36	
11	1.5	-4	125	34	2	-2.3	120	33	0	0	1.32	-0.04
12	1.5	-4	125	34	1.5	-3.3	120	33	0	0	1.21	
13	1.5	-4	125	34	1.5	-1.3	120	33	0	0	1.55	0.34
14	1.5	-4	125	34	1.5	-2.3	115	33	0	0	1.31	
15	1.5	-4	125	34	1.5	-2.3	125	33	0	0	1.35	0.04033
16	1.5	-4	125	34	1.5	-2.3	120	30	0	0	1.28	
17	1.5	-4	125	34	1.5	-2.3	120	36	0	0	1.39	0.11507
18	1.5	-4	125	34	1.5	-2.3	120	33	0	0		
19	1.5	-4	125	34	1.5	-2.3	120	33	0	0		0
20	1.5	-4	125	34	1.5	-2.3	120	33	0	0		
21	1.5	-4	125	34	1.5	-2.3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.205
Coefficient of variation of F,	$V_F$	0.154
Log normal reliability index,	$\beta_{LN}$	1.790
Reliability		0.963
Probability of failure		0.037

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.3188646	1.2417534	1.3113355	1.2762284
0.5	1.3315257	1.3315257	1.3315257	1.3315257
1	1.3431778	1.4286278	1.3516659	1.3913012



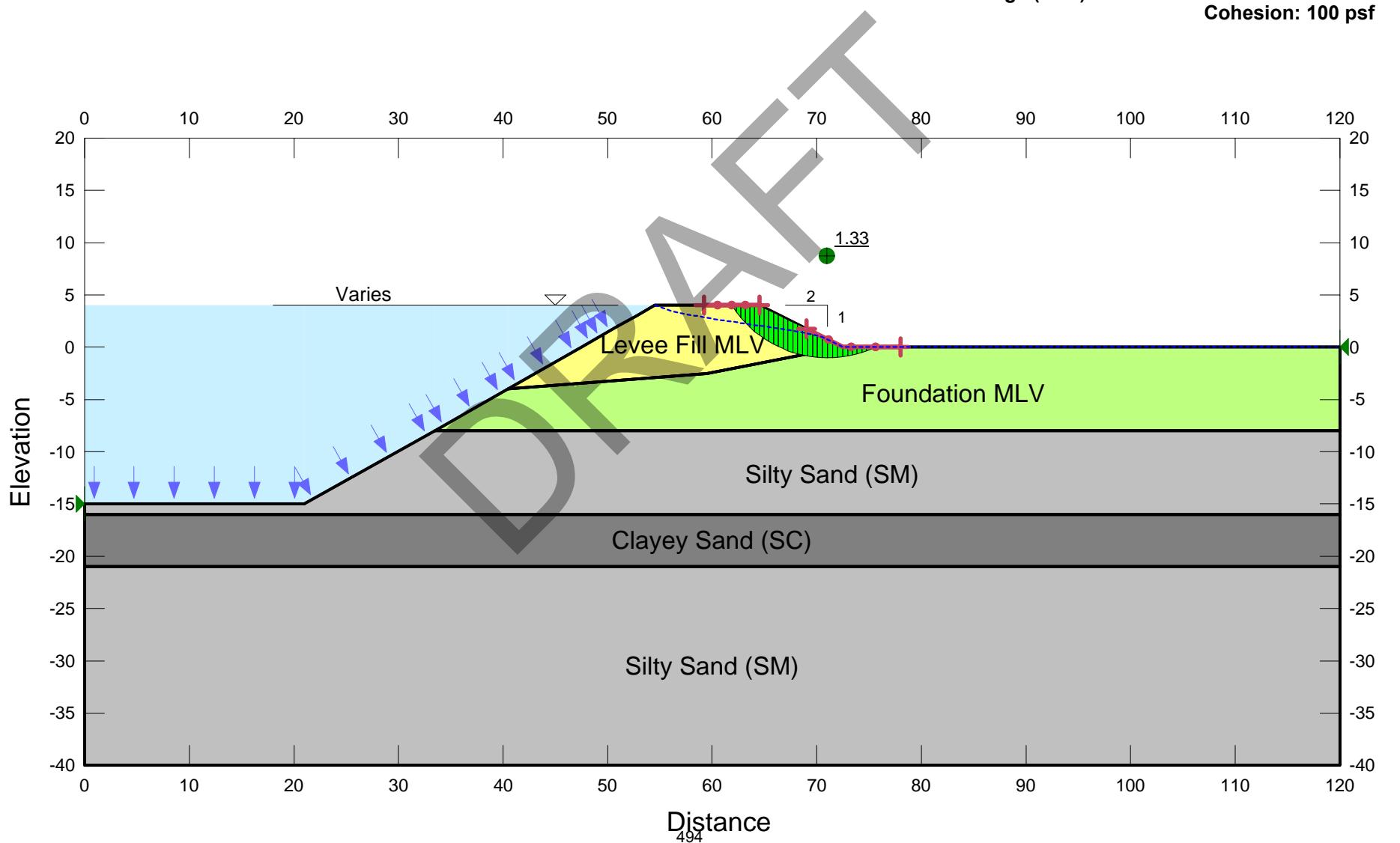
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Sportsmen
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Sportsmen Levee cross section from STA 27+00. Water Surface Elevation is 1 foot below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-4	cm/s	1
5	$\log(K_h)$ (Foundation)	-2.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0	5.19	
2	52.6	1.5	1.5	-4	-2.3	0	0	0	0	0	4.74	
3	62.6	1.5	1.5	-4	-2.3	0	0	0	0	0	5.65	0.90184
4	57.6	1	1.5	-4	-2.3	0	0	0	0	0	5.11	
5	57.6	2	1.5	-4	-2.3	0	0	0	0	0	5.27	0.16018
6	57.6	1.5	1	-4	-2.3	0	0	0	0	0	6.01	
7	57.6	1.5	2	-4	-2.3	0	0	0	0	0	4.71	-1.29613
8	57.6	1.5	1.5	-5	-2.3	0	0	0	0	0	6.74	
9	57.6	1.5	1.5	-3	-2.3	0	0	0	0	0	4.14	-2.60521
10	57.6	1.5	1.5	-4	-3.3	0	0	0	0	0	3.57	
11	57.6	1.5	1.5	-4	-1.3	0	0	0	0	0	9.76	6.18679
12	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
13	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
14	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
15	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
16	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
17	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
18	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
19	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
20	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
21	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	3.449
Coefficient of variation of F,	$V_F$	0.664
Log normal reliability index,	$\beta_{LN}$	2.424
Reliability		0.992
Probability of failure		0.008

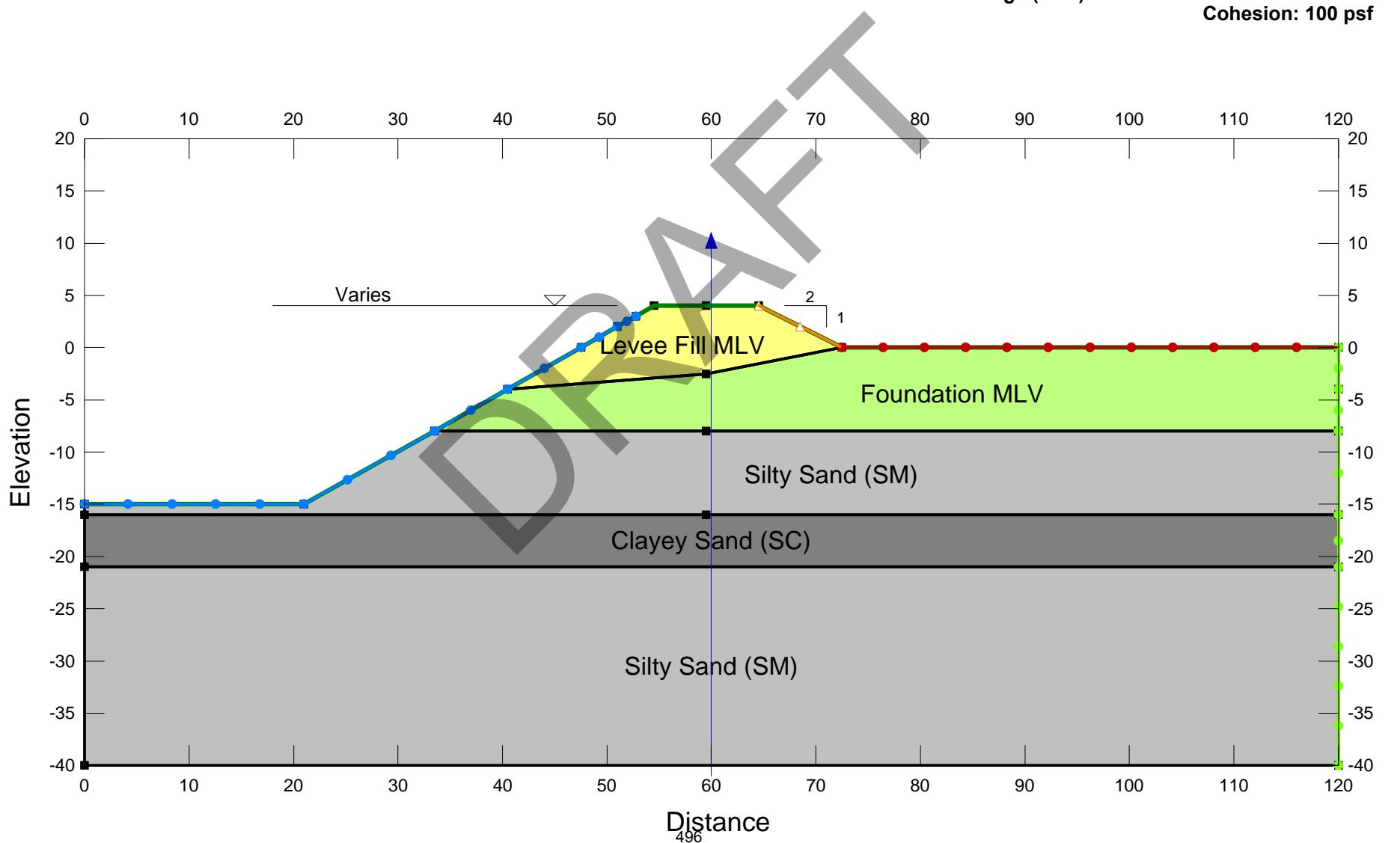
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



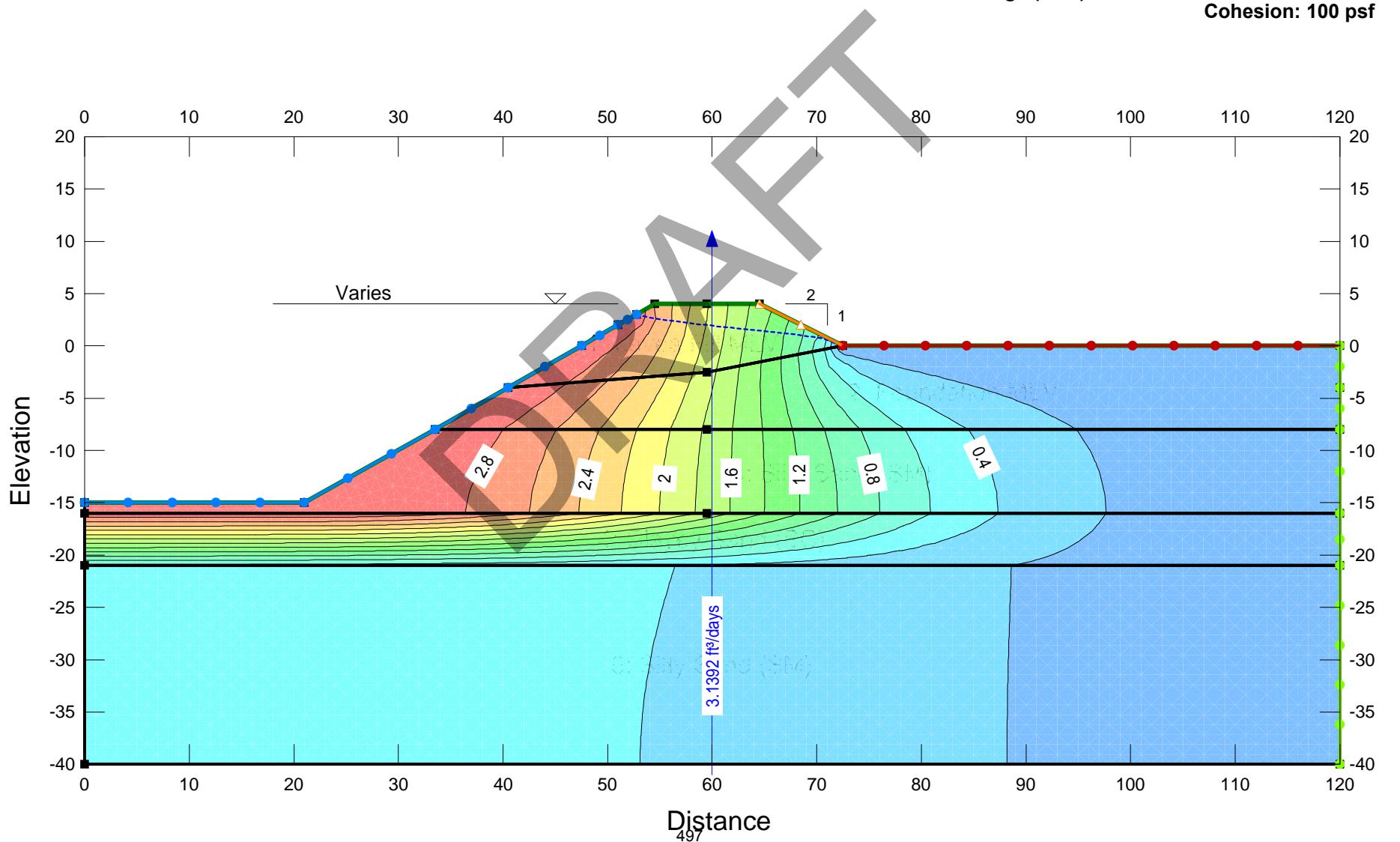
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



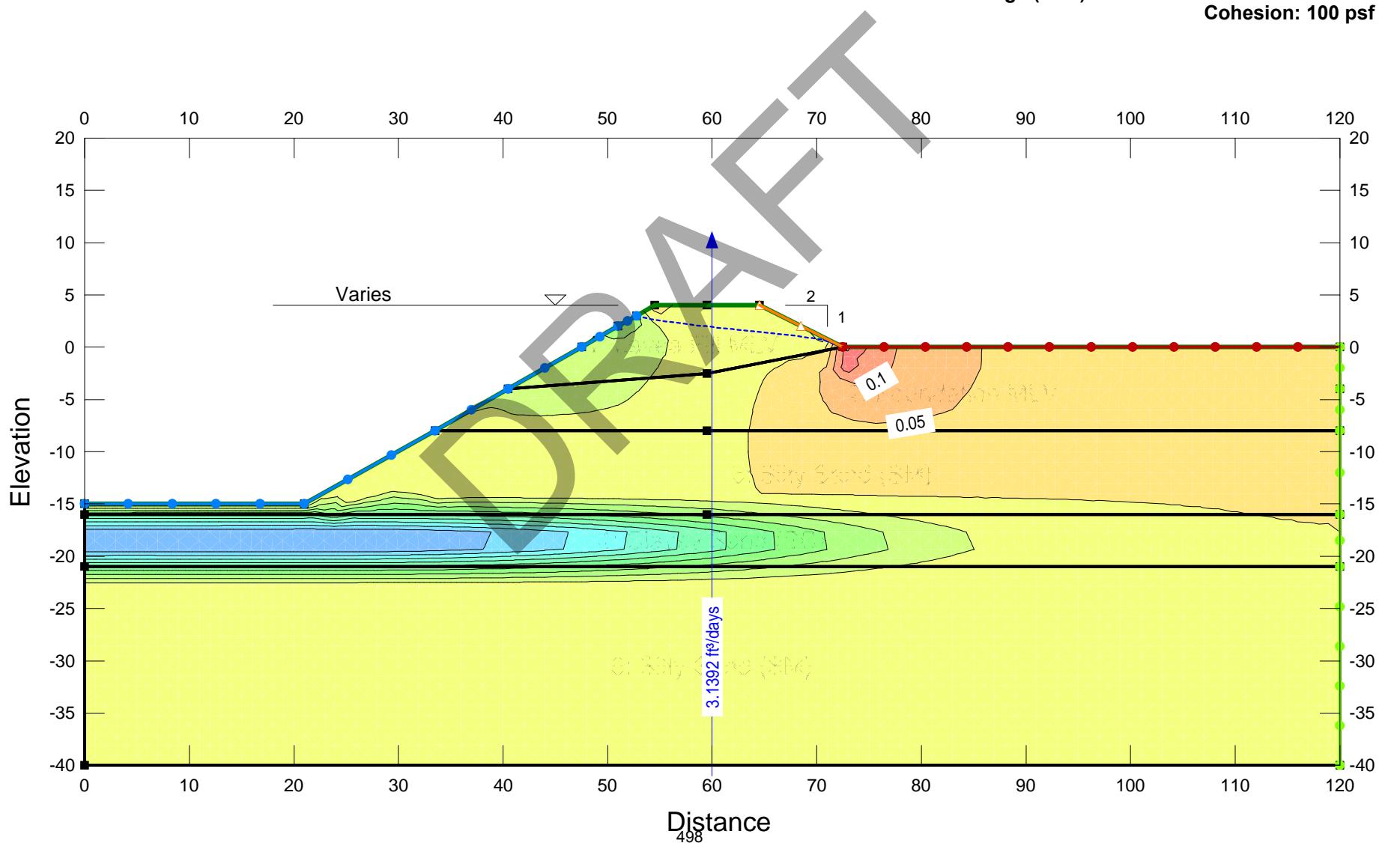
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
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**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



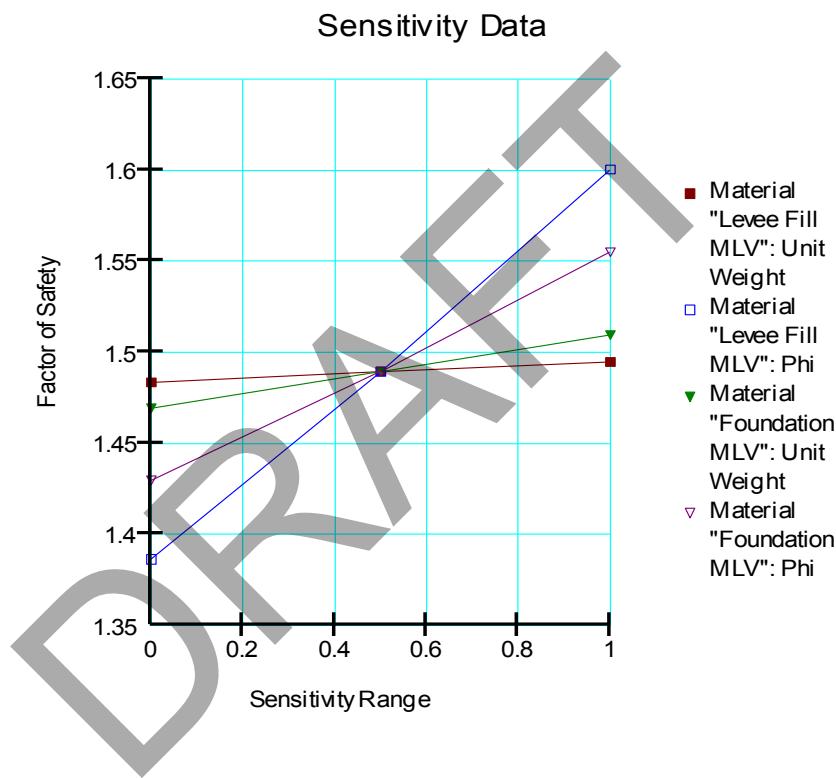
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Sportsmen
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Sportsmen Levee cross section from STA 27+00. Water Surface Elevation is 1 foot below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-4	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	34	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-4	125	34	1.5	-2.3	120	33	0	0	1.49	
2	1	-4	125	34	1.5	-2.3	120	33	0	0	1.48	
3	2	-4	125	34	1.5	-2.3	120	33	0	0	1.49	0.01
4	1.5	-5	125	34	1.5	-2.3	120	33	0	0	1.58	
5	1.5	-3	125	34	1.5	-2.3	120	33	0	0	1.63	0.05
6	1.5	-4	120	34	1.5	-2.3	120	33	0	0	1.48	
7	1.5	-4	130	34	1.5	-2.3	120	33	0	0	1.49	0.01137
8	1.5	-4	125	31	1.5	-2.3	120	33	0	0	1.39	
9	1.5	-4	125	37	1.5	-2.3	120	33	0	0	1.60	0.21399
10	1.5	-4	125	34	1	-2.3	120	33	0	0	1.50	
11	1.5	-4	125	34	2	-2.3	120	33	0	0	1.48	-0.02
12	1.5	-4	125	34	1.5	-3.3	120	33	0	0	1.35	
13	1.5	-4	125	34	1.5	-1.3	120	33	0	0	1.63	0.28
14	1.5	-4	125	34	1.5	-2.3	115	33	0	0	1.47	
15	1.5	-4	125	34	1.5	-2.3	125	33	0	0	1.51	0.0402
16	1.5	-4	125	34	1.5	-2.3	120	30	0	0	1.43	
17	1.5	-4	125	34	1.5	-2.3	120	36	0	0	1.55	0.12525
18	1.5	-4	125	34	1.5	-2.3	120	33	0	0		
19	1.5	-4	125	34	1.5	-2.3	120	33	0	0		0
20	1.5	-4	125	34	1.5	-2.3	120	33	0	0		
21	1.5	-4	125	34	1.5	-2.3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.190
Coefficient of variation of F,	$V_F$	0.128
Log normal reliability index,	$\beta_{LN}$	3.070
Reliability		0.999
Probability of failure		0.001

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.4834834	1.3864524	1.4692948	1.4296859
0.5	1.4894051	1.4894051	1.4894051	1.4894051
1	1.49485	1.6004467	1.5094911	1.5549357



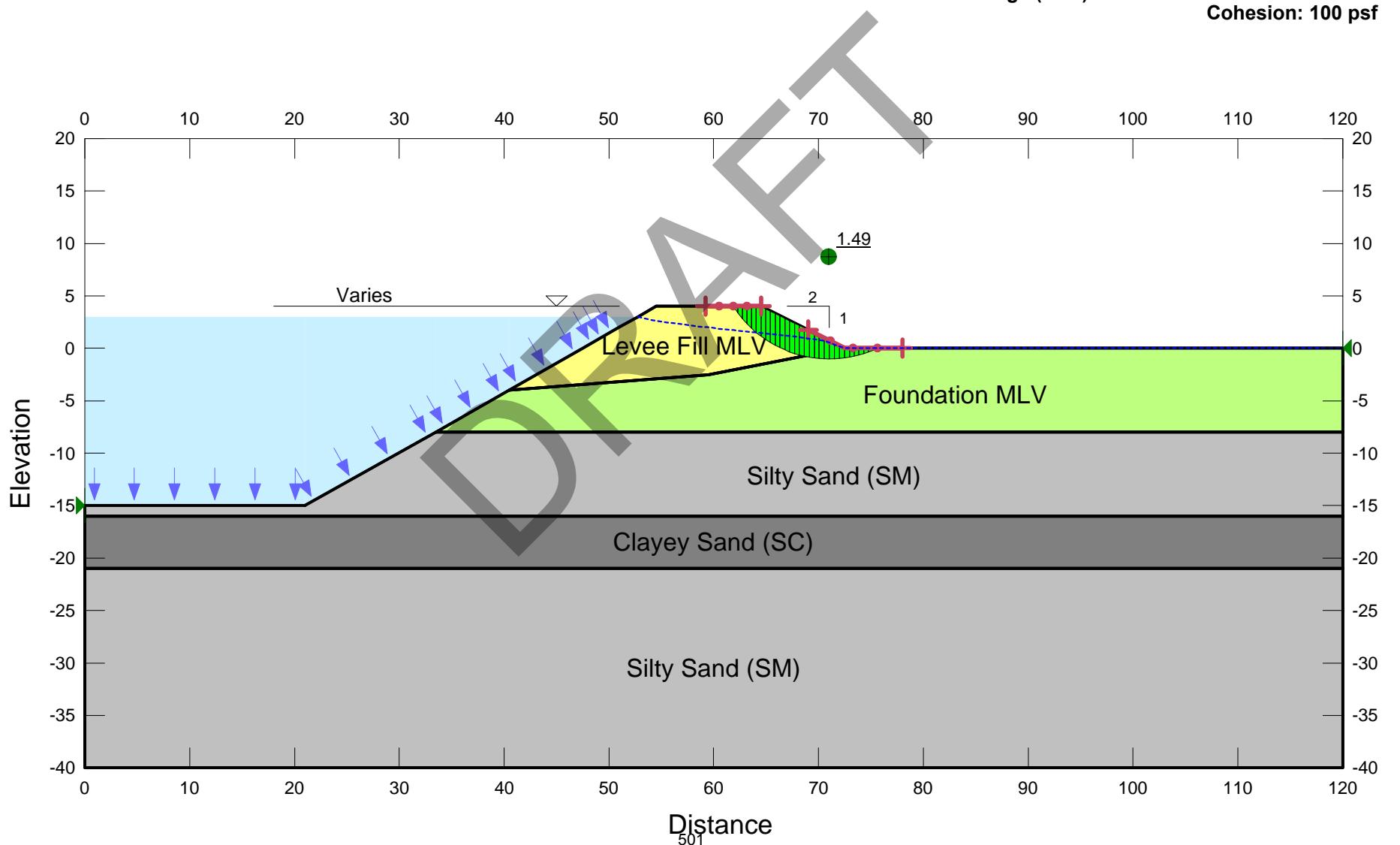
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Sportsmen
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Sportsmen Levee cross section from STA 27+00. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-4	cm/s	1
5	$\log(K_h)$ (Foundation)	-2.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0	8.15	
2	52.6	1.5	1.5	-4	-2.3	0	0	0	0	0	7.45	
3	62.6	1.5	1.5	-4	-2.3	0	0	0	0	0	8.86	1.41569
4	57.6	1	1.5	-4	-2.3	0	0	0	0	0	8.04	
5	57.6	2	1.5	-4	-2.3	0	0	0	0	0	8.23	0.19367
6	57.6	1.5	1	-4	-2.3	0	0	0	0	0	9.44	
7	57.6	1.5	2	-4	-2.3	0	0	0	0	0	7.38	-2.0597
8	57.6	1.5	1.5	-5	-2.3	0	0	0	0	0	10.26	
9	57.6	1.5	1.5	-3	-2.3	0	0	0	0	0	6.30	-3.95554
10	57.6	1.5	1.5	-4	-3.3	0	0	0	0	0	5.43	
11	57.6	1.5	1.5	-4	-1.3	0	0	0	0	0	15.38	9.95475
12	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
13	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
14	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
15	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
16	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
17	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
18	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
19	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
20	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		
21	57.6	1.5	1.5	-4	-2.3	0	0	0	0	0		

Standard deviation of F,	$\sigma_F$	5.501
Coefficient of variation of F,	$V_F$	0.675
Log normal reliability index,	$\beta_{LN}$	3.121
Reliability		0.999
Probability of failure		9.0E-04

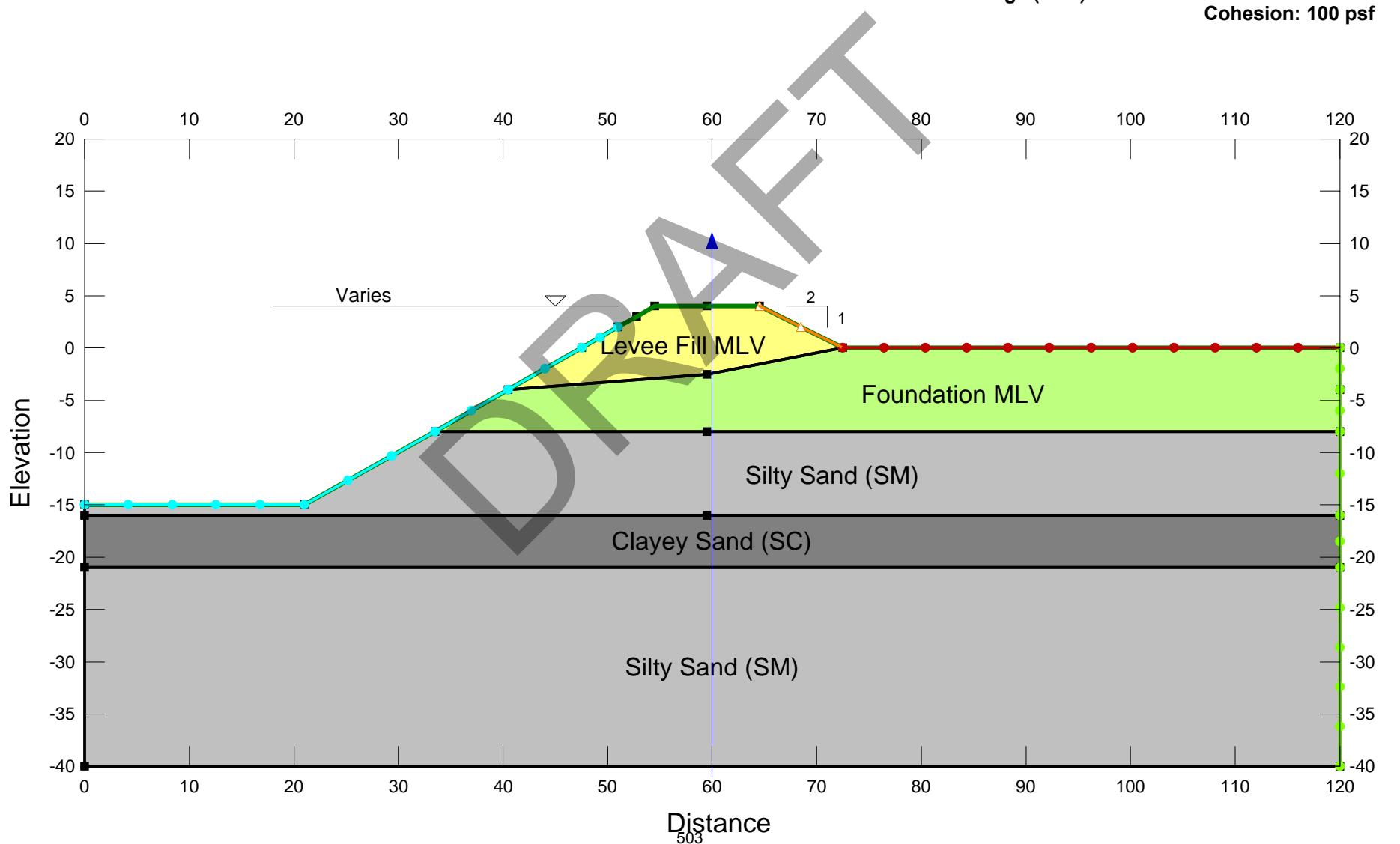
**Sportsmen Levee  
Puyallup River  
STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



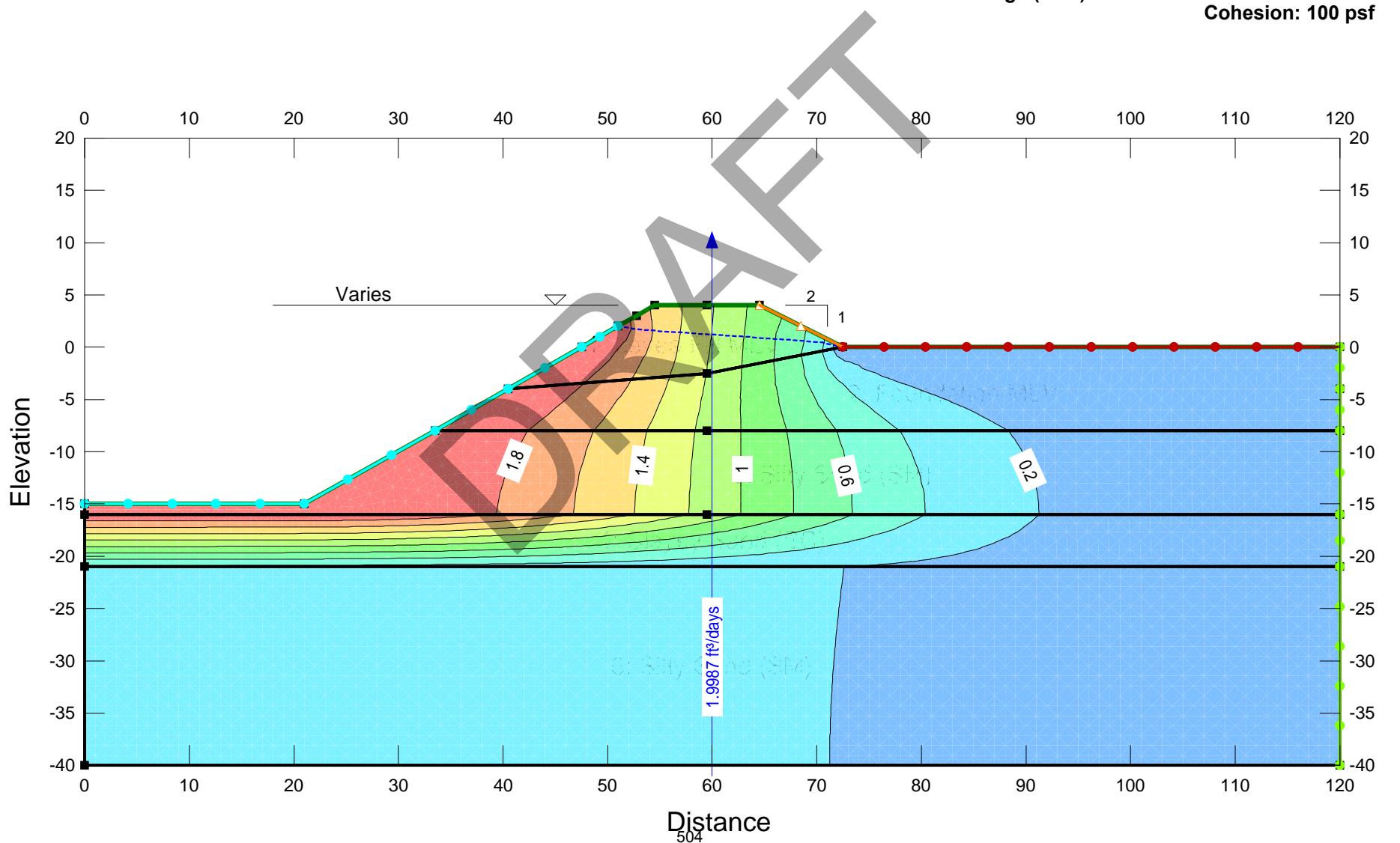
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 120 pcf  
 Phi: 32 degs

**Levee Foundation (SM)**  
 log(K-Sat): -2.3 cm/s (+/- 1)  
 KH/KV Ratio: 2.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 33 degs (+/- 3)

**Clayey Sand (SC)**  
 log(K-Sat): -5 cm/s  
 KH/KV Ratio: 2.5  
 Unit Weight: 115 pcf  
 Phi: 32 degs  
 Cohesion: 100 psf



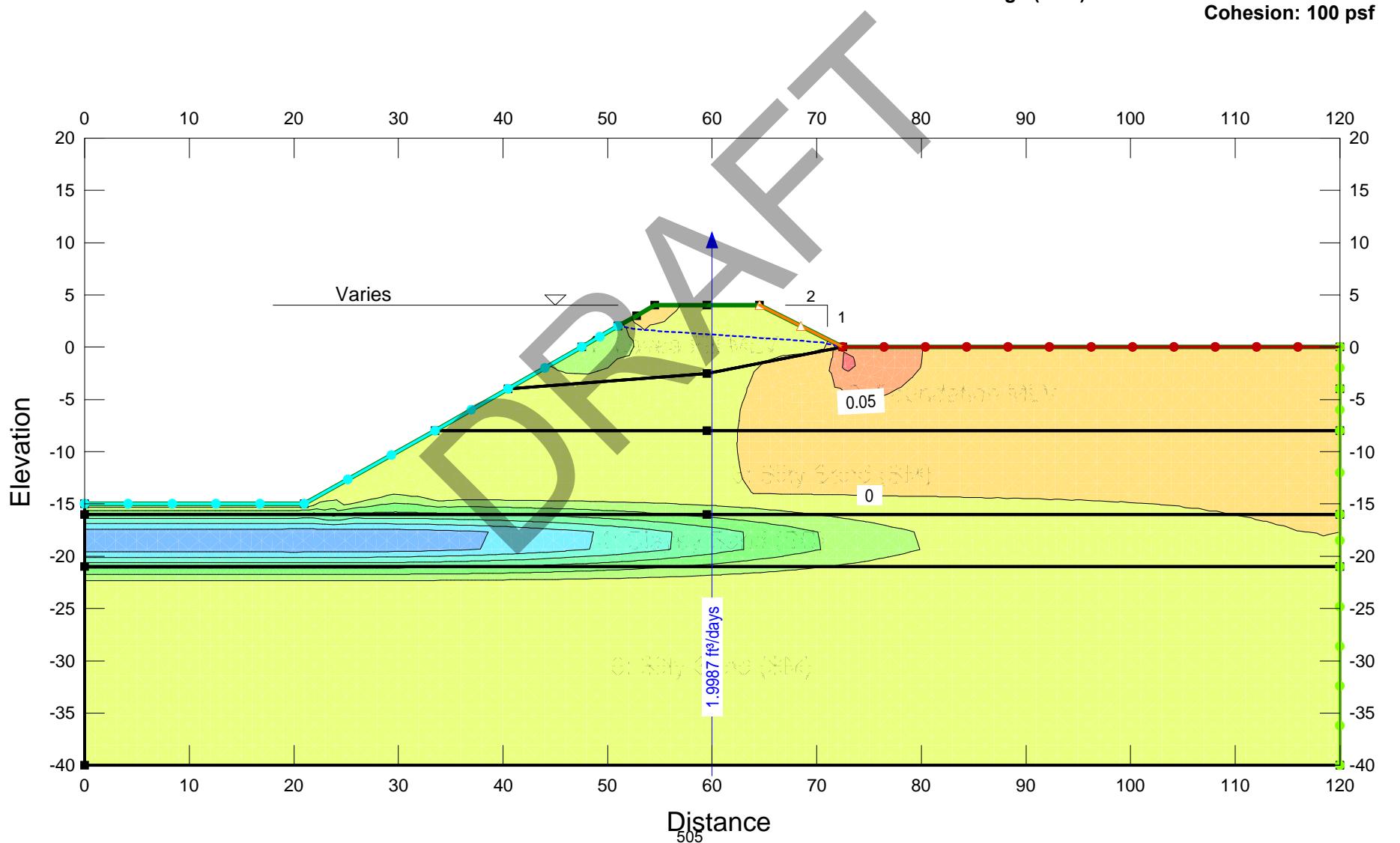
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 125 pcf (+/- 5)  
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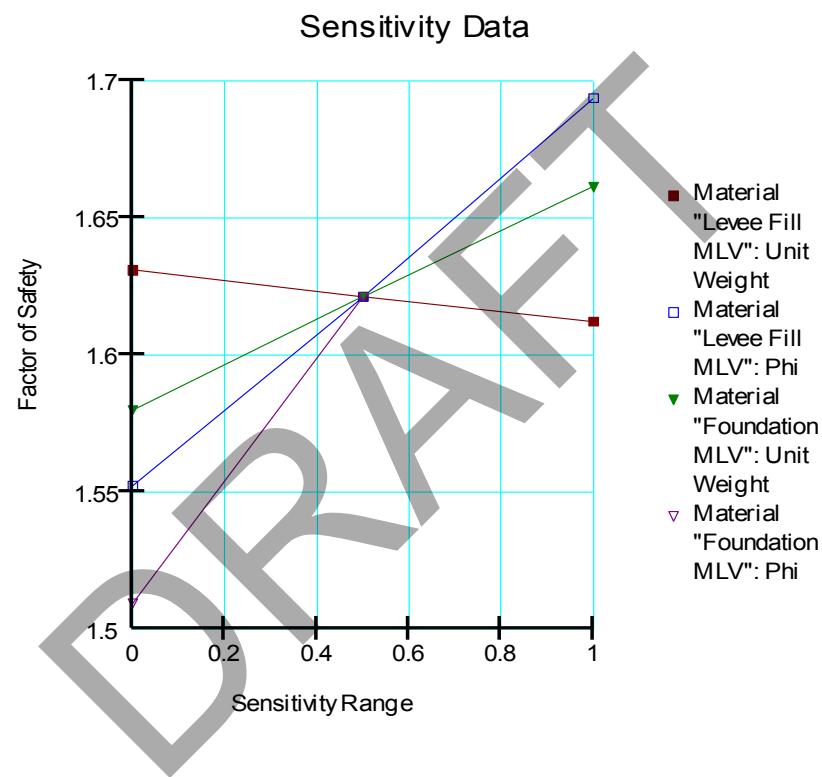
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Sportsmen
Date	8-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Sportsmen Levee cross section from STA 27+00. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-4	cm/s	1
3	$\gamma_{sat}$ (Fill)	125	pcf	5
4	$\phi'$ (Fill)	34	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-2.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	33	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-4	125	34	1.5	-2.3	120	33	0	0	1.62	
2	1	-4	125	34	1.5	-2.3	120	33	0	0	1.61	
3	2	-4	125	34	1.5	-2.3	120	33	0	0	1.62	0.01
4	1.5	-5	125	34	1.5	-2.3	120	33	0	0	1.66	
5	1.5	-3	125	34	1.5	-2.3	120	33	0	0	1.83	0.17
6	1.5	-4	120	34	1.5	-2.3	120	33	0	0	1.63	
7	1.5	-4	130	34	1.5	-2.3	120	33	0	0	1.61	-0.01872
8	1.5	-4	125	31	1.5	-2.3	120	33	0	0	1.55	
9	1.5	-4	125	37	1.5	-2.3	120	33	0	0	1.69	0.14123
10	1.5	-4	125	34	1	-2.3	120	33	0	0	1.63	
11	1.5	-4	125	34	2	-2.3	120	33	0	0	1.60	-0.03
12	1.5	-4	125	34	1.5	-3.3	120	33	0	0	1.52	
13	1.5	-4	125	34	1.5	-1.3	120	33	0	0	1.70	0.18
14	1.5	-4	125	34	1.5	-2.3	115	33	0	0	1.58	
15	1.5	-4	125	34	1.5	-2.3	125	33	0	0	1.66	0.0813
16	1.5	-4	125	34	1.5	-2.3	120	30	0	0	1.51	
17	1.5	-4	125	34	1.5	-2.3	120	36	0	0	1.74	0.23054
18	1.5	-4	125	34	1.5	-2.3	120	33	0	0		
19	1.5	-4	125	34	1.5	-2.3	120	33	0	0		0
20	1.5	-4	125	34	1.5	-2.3	120	33	0	0		
21	1.5	-4	125	34	1.5	-2.3	120	33	0	0		0

Standard deviation of F,	$\sigma_F$	0.189
Coefficient of variation of F,	$V_F$	0.116
Log normal reliability index,	$\beta_{LN}$	4.109
Reliability		1.000
Probability of failure		2.0E-05

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.6310132	1.5524749	1.5799973	1.5094605
0.5	1.6213056	1.6213056	1.6213056	1.6213056
1	1.6122896	1.6937071	1.6612941	1.74



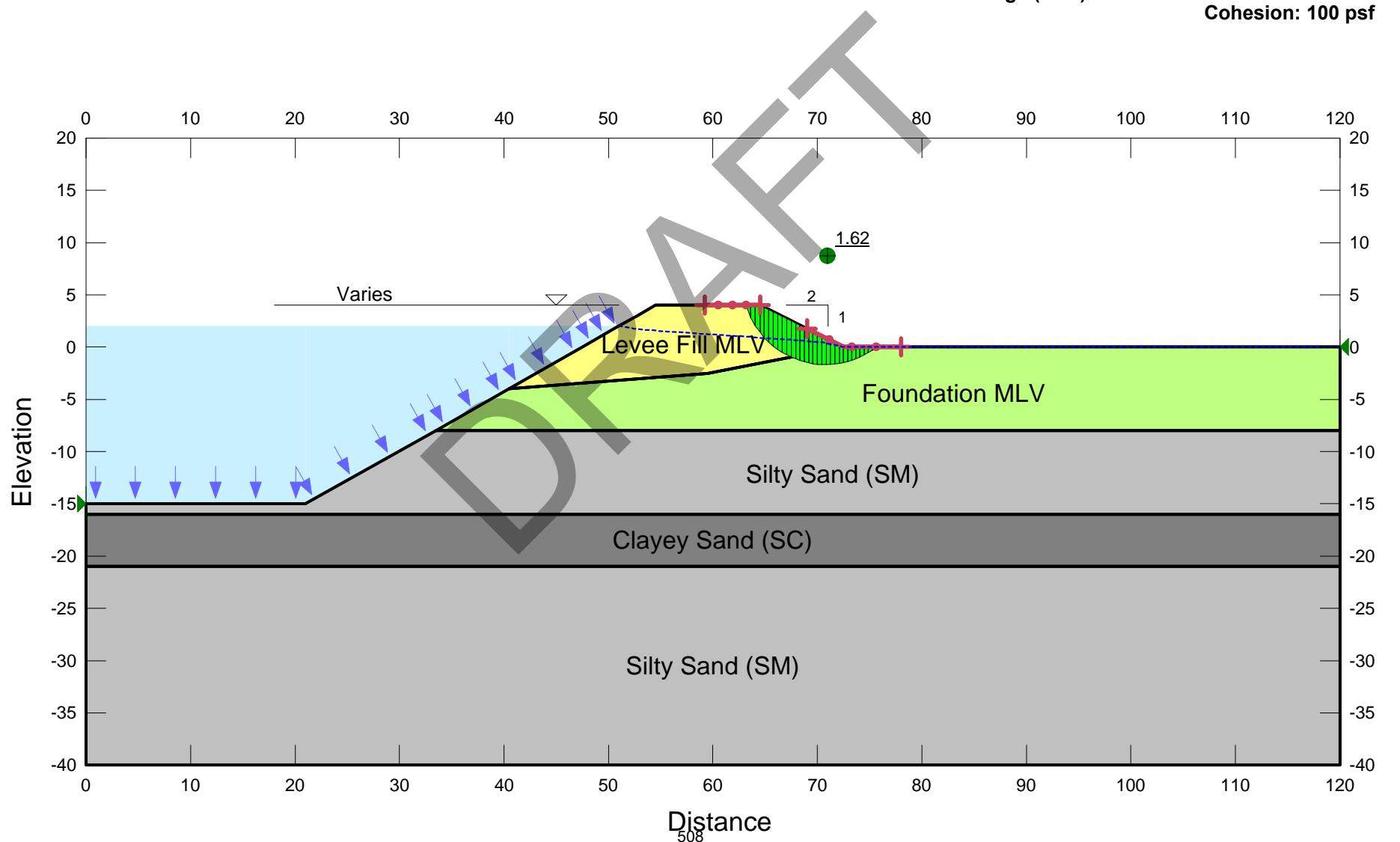
**Sportsmen Levee**  
**Puyallup River**  
**STA 27+00**

**Levee Fill (GM)**  
 log(K-Sat): -4 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
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**Silty Sand (SM)**  
 log(K-Sat): -4 cm/s  
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 Unit Weight: 120 pcf  
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 Cohesion: 100 psf



# PUYALLUP BASIN GENERAL INVESTIGATION

## FRAGILITY CURVE ANALYSIS

### Method of Analysis

Water Ski Cross Section Model & Erosion Analysis

#### General Information

<b>Location:</b>	Pierce County, Washington
<b>River:</b>	Carbon River
<b>Levee Segment Name:</b>	Water Ski
<b>Station:</b>	43+87

#### Levee Condition Factor

Levee Condition Factor	1
------------------------	---

**Remarks:** Levee is deemed a 1 because the levee is acceptable per USACE guidance. No maintenance issues were noted.

#### Levee Geometry

Crown Width (W)	19 Feet
Landward Levee Height (H)	5 Feet
Riverward Slope (R)	3 H:1V
Landward Slope (L)	3 H:1V

#### Breach Characteristics

Levee Material Type	
X	Generally Cohesionless
	Generally Cohesive
Breach Depth	5 Feet
Breach Width at Top of Levee	112 Feet*
Breach Side Slope	2V:1H
Time to Full Development	1.97 Hours*

\*SERRI Report 70015-001

#### Levee Soil Parameters

##### Foundation Type

X	Homogeneous Foundation
	Interbedded Foundation
	Layered Foundation

**Remarks:** Levee foundation is a dense poorly graded SAND with silt (SP-SM) alluvium.

##### Embankment Material

Density ( $\gamma$ )		Soil Strength ( $\phi$ )	
	Loose / Soft		Low
	Medium		Medium
X	Dense / Stiff	X	High

**Remarks:** Levee embankment material is a dense silty GRAVEL with sand (GM).

#### Flood Fighting Ability

##### Underseepage and Piping Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

##### Landward Slope Instability Failure Mode

Flood Fighting Ability?	Yes	X	No
-------------------------	-----	---	----

**Remarks:** Flood fighting ability is expected. But, the adjustment factor was not included in the fragility curve for this assessment.

#### Adjustment Factors

##### Initiation vs. Breach

Piping Factor	0.18*
Sliding Factor	0.83*

\*Expert Elicitation

##### Flood Fighting

Piping Factor	0.03*
Sliding Factor	0.28*

\*Expert Elicitation

#### Duration Trigger

5 Days*
*Expert Elicitation

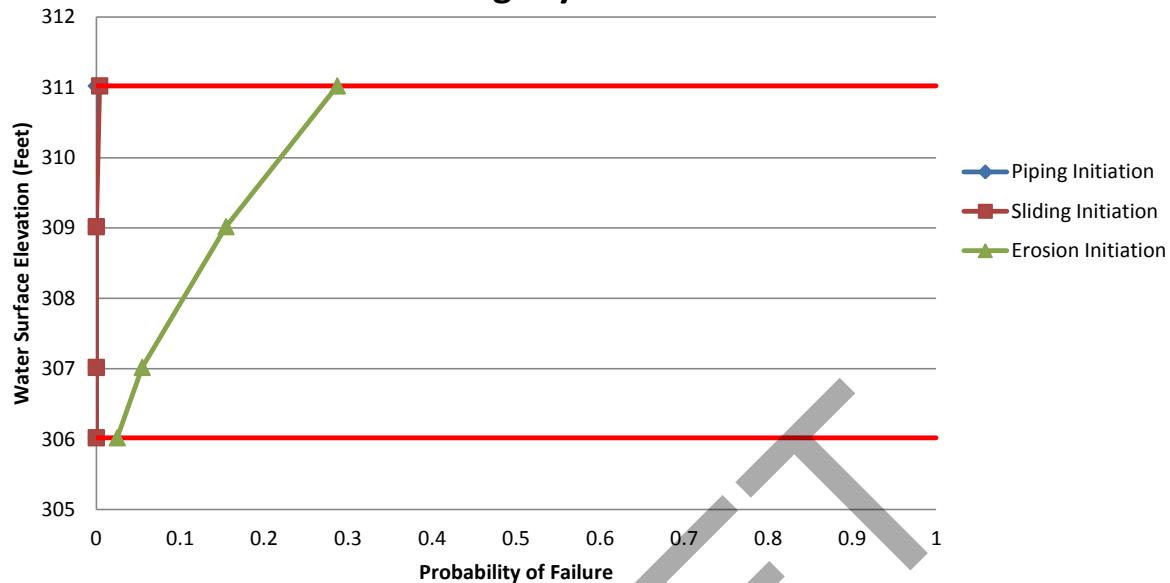
#### Final Fragility Curve

Elev.	Prob.
311.02	1.00
311.02	0.29
309.02	0.15
307.02	0.05
306.02	0.03

# PUYALLUP BASIN GENERAL INVESTIGATION

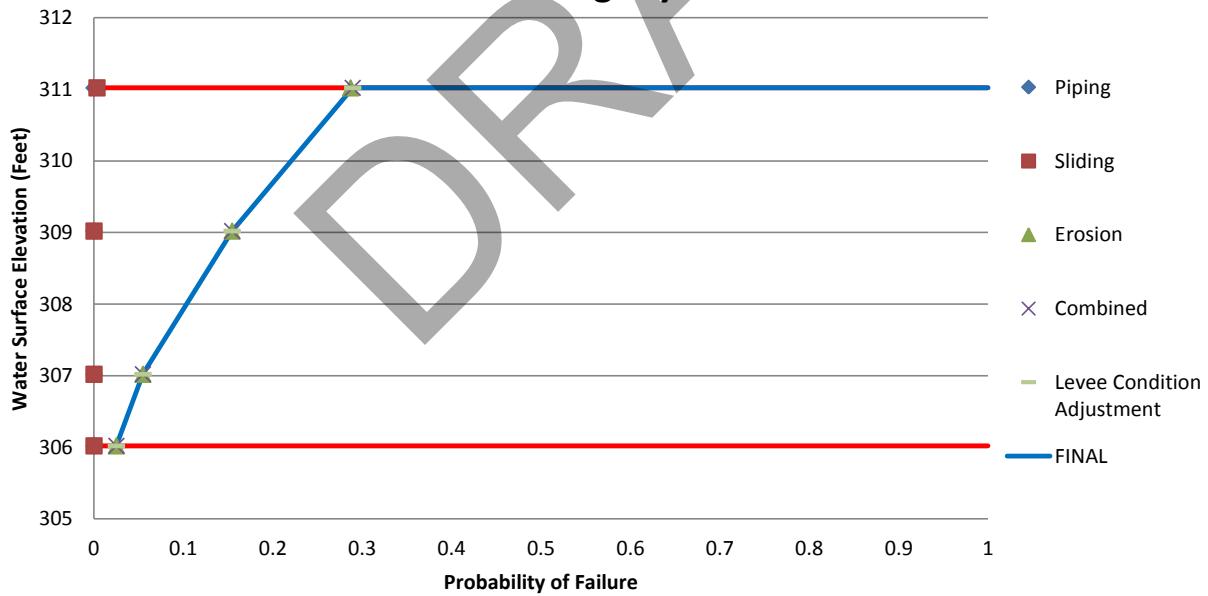
## FRAGILITY CURVE ANALYSIS

### Levee Fragility Curve - Initiation



*Remarks:* Fragility curve above displays the fragility curve at initiation only. No adjustments.

### Levee Fragility Curve



*Remarks:* The final levee fragility curve for the Water Ski Levee was adjusted with an initiation to breach factor to account for the probability associated with an initiated failure mode progressing to full breach. Levee condition was found not to significantly increase the probability of failure. Finally, flood fighting adjustment factors were ignored in this analysis.

# Water Ski Levee - Carbon River



**DISCLAIMER:** While the United States Army Corps of Engineers, (hereinafter referred to as USACE) has made a reasonable effort to insure the accuracy of the maps and associated data, it should be explicitly noted that USACE makes no warranty, representation or guarantee, expressed or implied, as to the absolute, semantic, accuracy, timeliness or completeness of any of the data provided herein. The USACE, its officers, agents, employees, or servants shall assume no liability of any nature for any errors, omissions, or inaccuracies in the information provided regardless of how caused. The USACE, its officers, agents, employees or servants shall assume no liability for damages resulting from the use of the maps and associated data. The user of the maps and associated data is responsible for taking full responsibility for the use of the maps and associated data in reliance upon any information or data furnished here. By using these maps and associated data the user does so entirely at their own risk and explicitly acknowledges that he/she is aware of and agrees to be bound by this disclaimer and agrees not to present any claim or demands of any kind against the USACE, its officers, agents, employees, or servants, in any forum whatsoever for any damages of any nature whatsoever that may result from or may be caused in any way by the use of the maps and associated data.

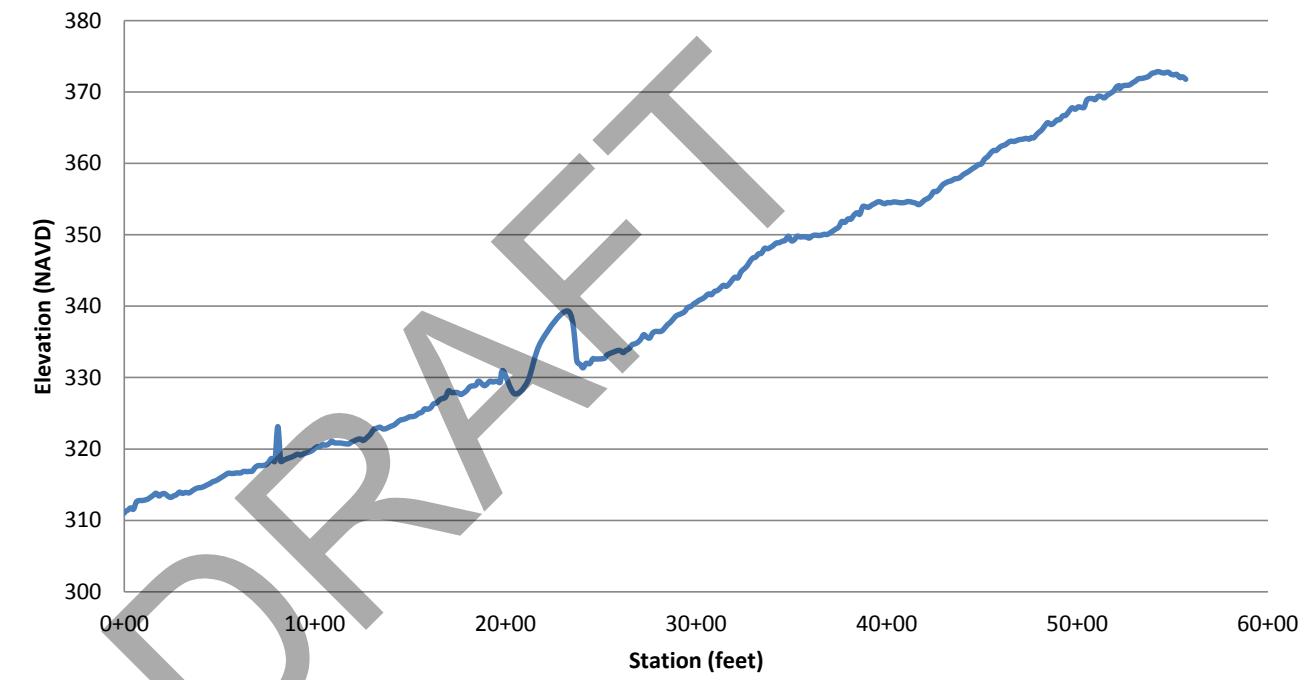
## Water Ski Levee

### Carbon River

<b>Min</b>	311.02
<b>Max</b>	372.84

<b>Station Begin</b>	0+00
<b>Station End</b>	55+69

### Levee Profile



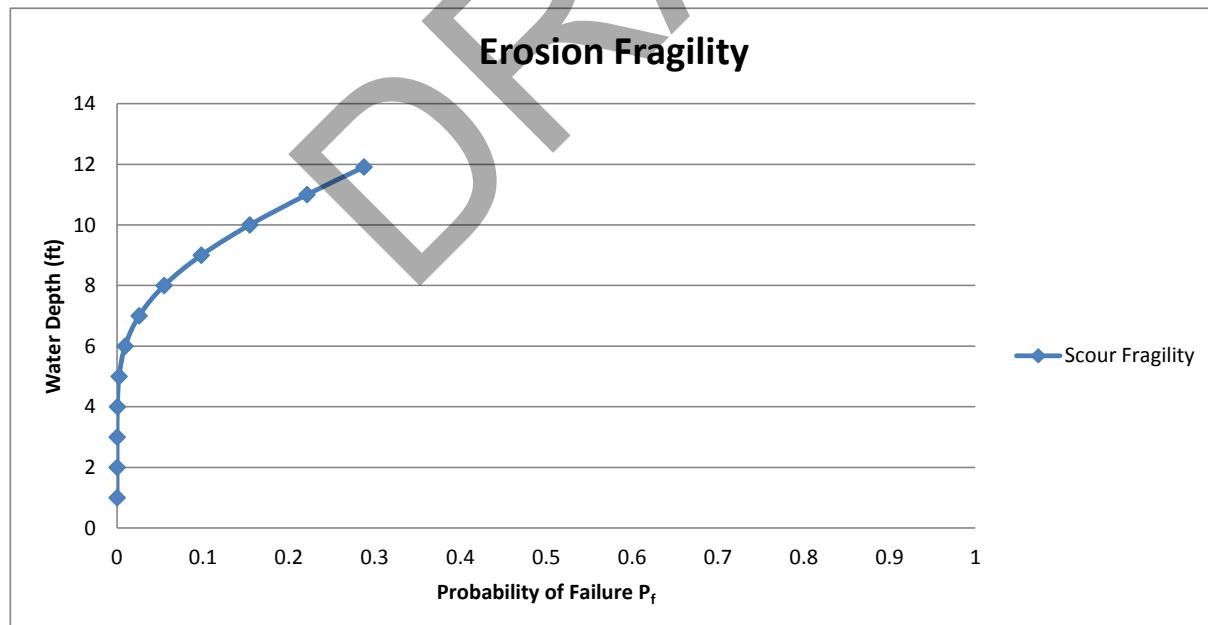
\* Profile Elevations from 2010 survey.

## Surface Erosion Analysis

### Water Ski Levee

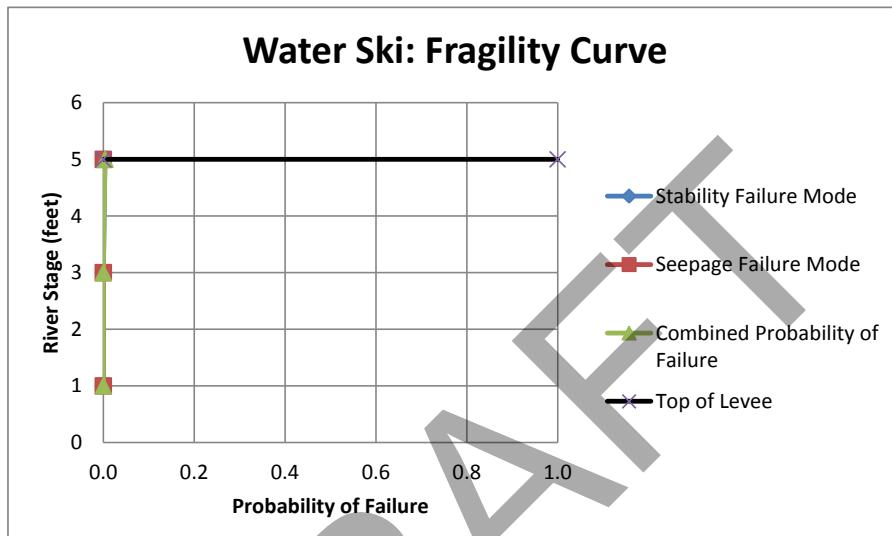
	Expected Value		Coefficient of Variation		Standard Deviation
Slope	S =	0.0107	CV(s) =	0.1	0.00107
Manning's "n"	n =	0.065	CV(n) =	0.15	0.00975
Scouring Velocity		V <sub>crit</sub> = 14.23	CV(V <sub>crit</sub> )		2.85

Water Height (y)	E(V) (ft/sec)	CV(v)		ln(E(v)/E(V <sub>crit</sub> ))	sqrt(CV <sub>crit</sub> <sup>2</sup> + CV <sup>2</sup> )	β	P <sub>f</sub>
0	0.000	0.1581139					
1	2.365	0.1581139		-1.794405391	0.254950976	-7.03824	9.7344E-13
2	3.754	0.1581139		-1.332307271	0.254950976	-5.22574	8.673E-08
3	4.919	0.1581139		-1.061997199	0.254950976	-4.1655	1.5534E-05
4	5.959	0.1581139		-0.870209151	0.254950976	-3.41324	0.00032098
5	6.915	0.1581139		-0.721446783	0.254950976	-2.82975	0.00232924
6	7.808	0.1581139		-0.599899078	0.254950976	-2.353	0.00931137
7	8.654	0.1581139		-0.497131959	0.254950976	-1.94991	0.02559331
8	9.459	0.1581139		-0.40811103	0.254950976	-1.60074	0.05471691
9	10.232	0.1581139		-0.329589006	0.254950976	-1.29275	0.098048
10	10.977	0.1581139		-0.259348663	0.254950976	-1.01725	0.15451746
11	11.697	0.1581139		-0.195808543	0.254950976	-0.76802	0.22123638
11.91	12.333	0.1581139		-0.142819802	0.254950976	-0.56019	0.28767651



Water Ski					
Fragility Curve					
Cross Section from STA 23+17					

Stability		Seepage		Combined	
Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>	Stage	P <sub>failure</sub>
OVERTOPPING - 5' +					
5	0.004	5	1.9E-05	5	0.004
3	2.6E-08	3	3.3E-07	3	0.000
1	0.0E+00	1	0.0E+00	1	0.000



OVERTOPPING - 5' +	
Top of Levee	
5	0
5	1

Soil Unit	Stability	TOL		TOL -2'		TOL -4'		Seepage
		Stability	Seepage	Stability	Seepage	Stability	Seepage	
1	MLV	1.64	0.19	1.92	0.11	2.14	0.04	MLV
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.68	0.19	1.95	0.11	2.16	0.04	yB -1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.66	0.19	1.94	0.11	2.15	0.04	yB +1SD
	log(K <sub>h</sub> )-1SD	1.84	0.20	2.01	0.11	2.16	0.04	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	log(K <sub>h</sub> )+1SD	1.46	0.17	1.77	0.11	2.09	0.04	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	$\gamma$ -1SD	1.63	0.22	1.92	0.10	2.14	0.04	(K <sub>h</sub> /K <sub>v</sub> )-1SD
	$\gamma$ +1SD	1.66	0.27	1.92	0.12	2.13	0.04	(K <sub>h</sub> /K <sub>v</sub> )+1SD
	$\phi$ -1SD	1.56	0.15	1.82	0.09	2.03	0.10	log(K <sub>h</sub> )-1SD
2	$\phi$ +1SD	1.73	0.23	2.03	0.15	2.25	0.05	log(K <sub>h</sub> )+1SD
	(K <sub>h</sub> /K <sub>v</sub> )-1SD	1.70	0.23	1.94	0.15	2.14	0.05	log(K <sub>h</sub> )-1SD
	(K <sub>h</sub> /K <sub>v</sub> )+1SD	1.62	0.15	1.90	0.09	2.13	0.06	log(K <sub>h</sub> )+1SD
	log(K <sub>h</sub> )-1SD	1.46	(i)	1.77	(i)	2.09	(i)	
	log(K <sub>h</sub> )+1SD	1.82		2.00		2.16		
	$\gamma$ -1SD	1.62		1.89		2.11		
	$\gamma$ +1SD	1.67		1.95		2.16		
	$\gamma$ -1SD	1.55		1.81		2.01		
	$\gamma$ +1SD	1.75		2.04		2.27		

Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Water Ski
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	$F = \text{buoyant unit wt} / (\text{exit gradient} * \text{unit wt water})$
Notes:	Water Ski cross section from STA 43+87. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{\text{buoyant}}$	57.6	pcf	5
2	$(K_v/K_v) \text{ (Fill)}$	1.5	unitless	0.5
3	$(K_v/K_v) \text{ (Foundation)}$	1.5	unitless	0.5
4	$\log(K_h) \text{ (Fill)}$	-3.3	cm/s	1
5	$\log(K_h) \text{ (Foundation)}$	-3.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	4.76	
2	52.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	4.35	
3	62.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	5.18	0.83
4	57.6	1	1.5	-3.3	-3.3	0	0	0	0	0	4.68	
5	57.6	2	1.5	-3.3	-3.3	0	0	0	0	0	5.51	0.83091
6	57.6	1.5	1	-3.3	-3.3	0	0	0	0	0	4.29	
7	57.6	1.5	2	-3.3	-3.3	0	0	0	0	0	3.43	-0.85788
8	57.6	1.5	1.5	-4.3	-3.3	0	0	0	0	0	6.33	
9	57.6	1.5	1.5	-2.3	-3.3	0	0	0	0	0	4.02	-2.31075
10	57.6	1.5	1.5	-3.3	-4.3	0	0	0	0	0	4.02	
11	57.6	1.5	1.5	-3.3	-2.3	0	0	0	0	0	6.33	2.3125
12	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		

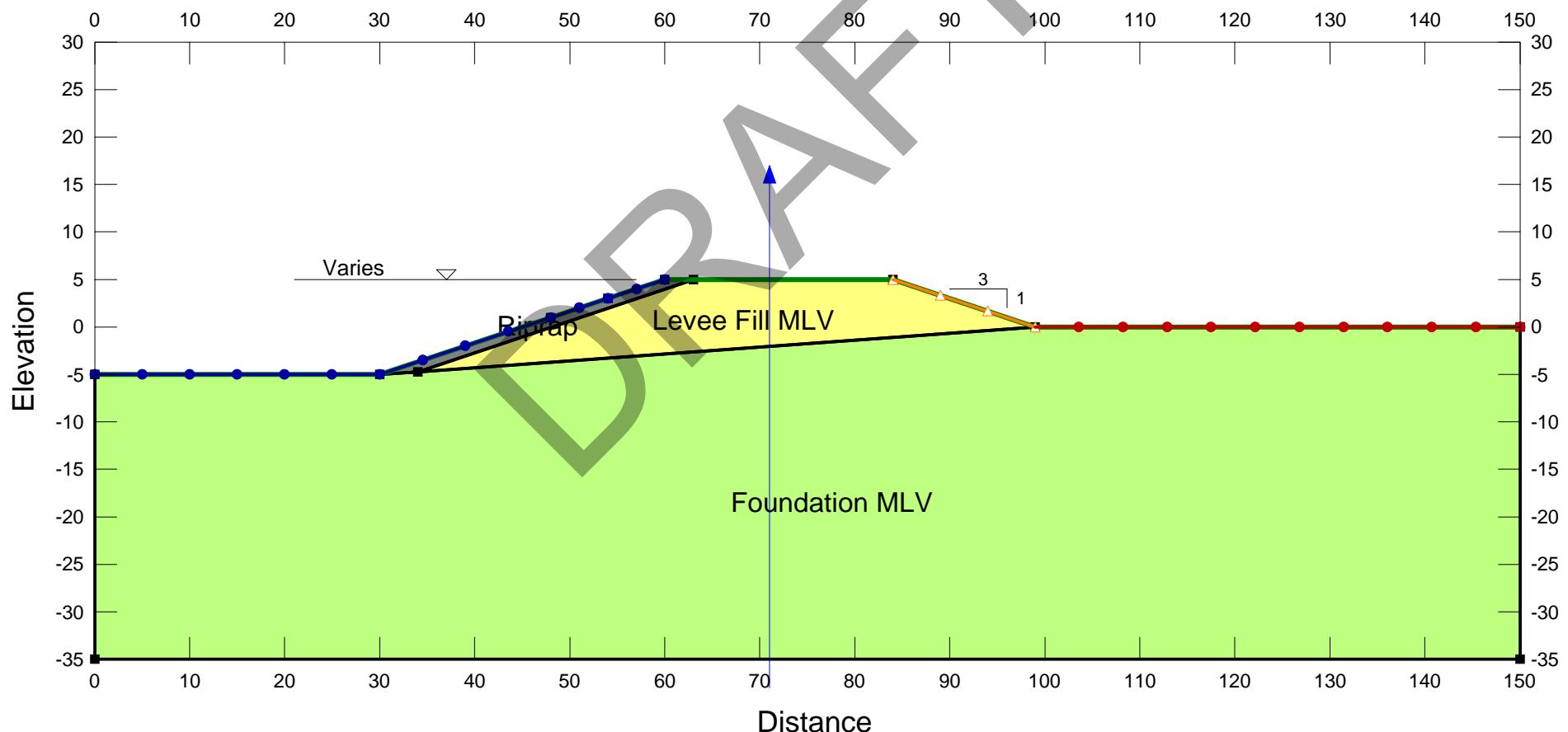
Standard deviation of F,	$\sigma_F$	1.789
Coefficient of variation of F,	$V_F$	0.376
Log normal reliability index,	$\beta_{LN}$	4.116
Reliability		1.000
Probability of failure		1.9E-05

**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SP-SM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

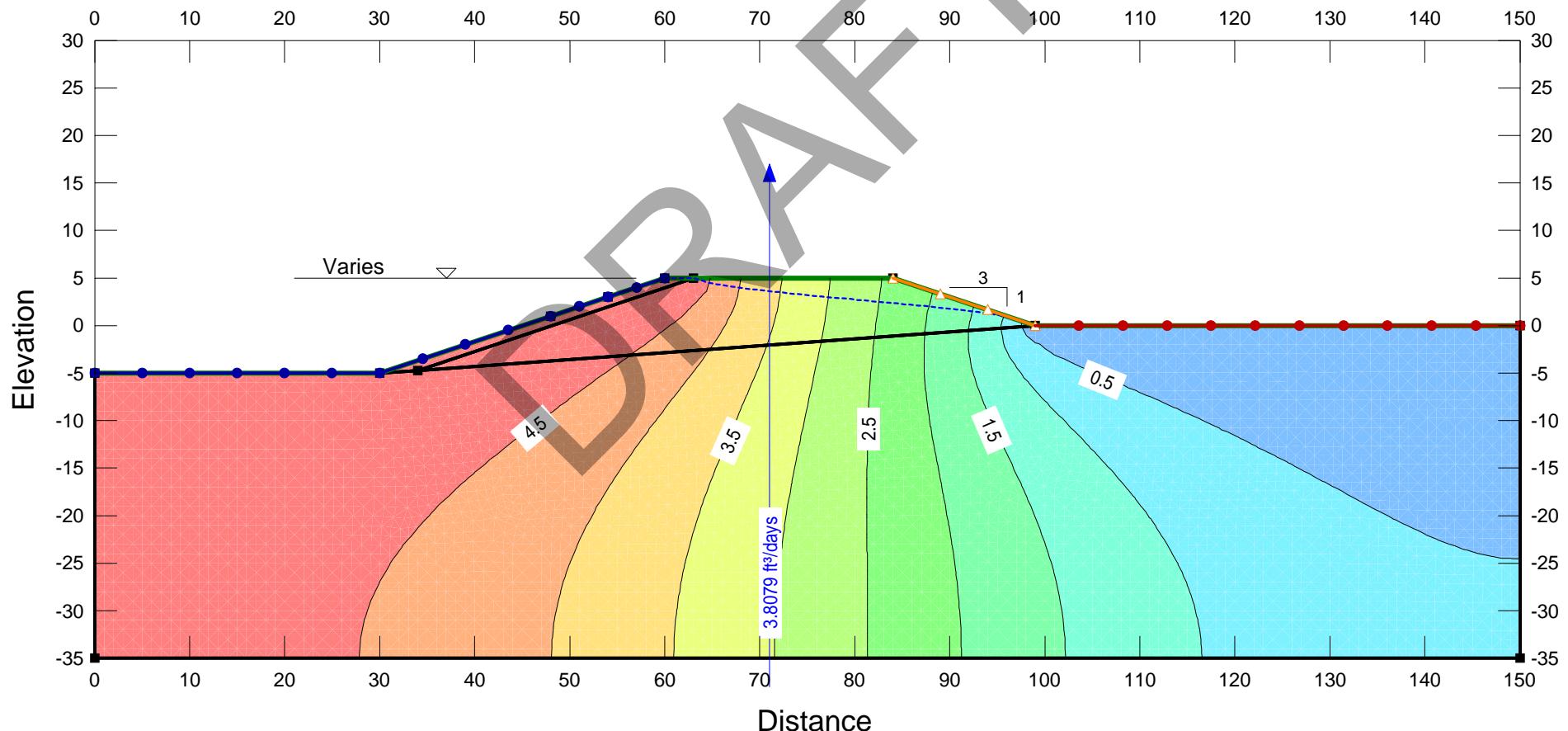


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 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

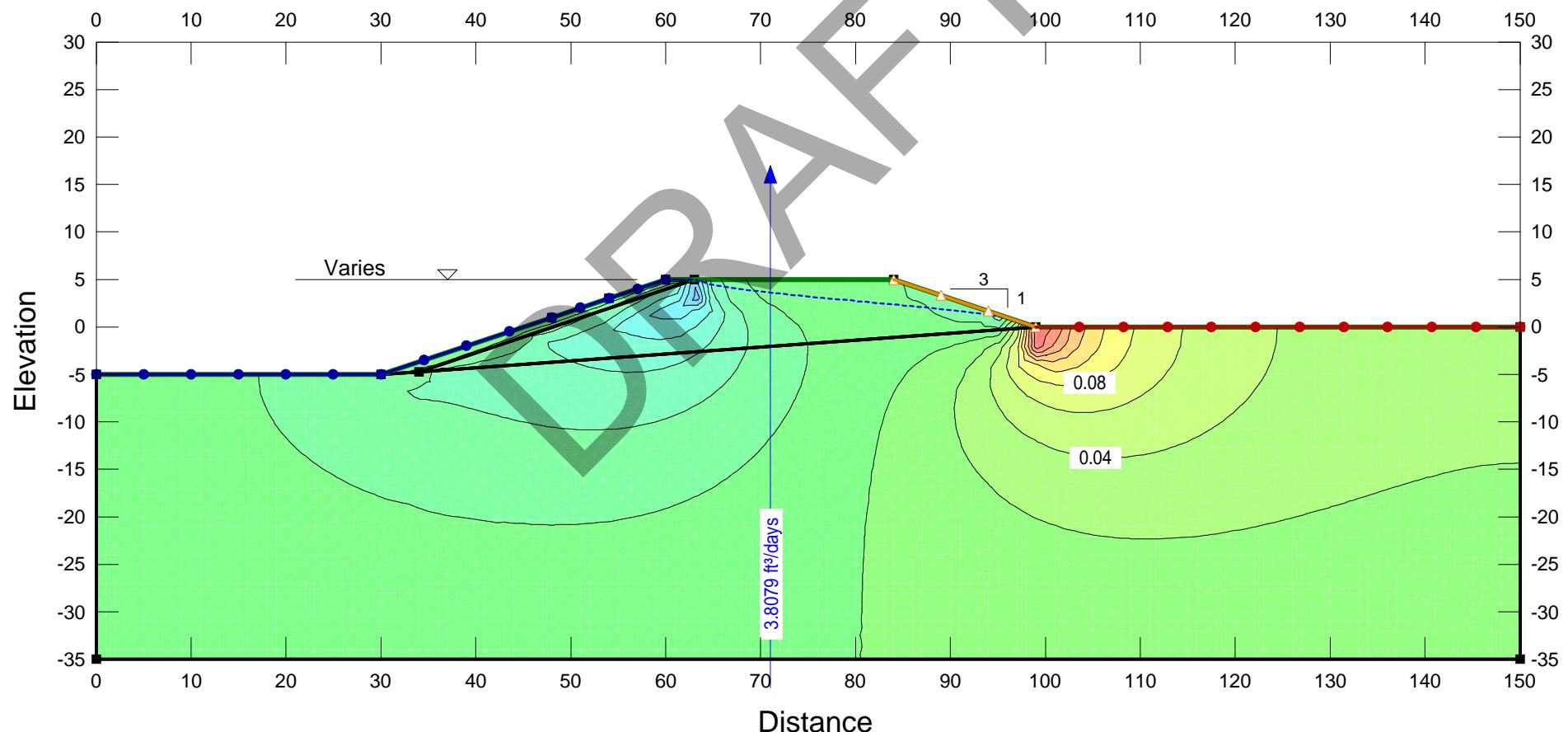


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SP-SM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)



**Taylor's series method spreadsheet**

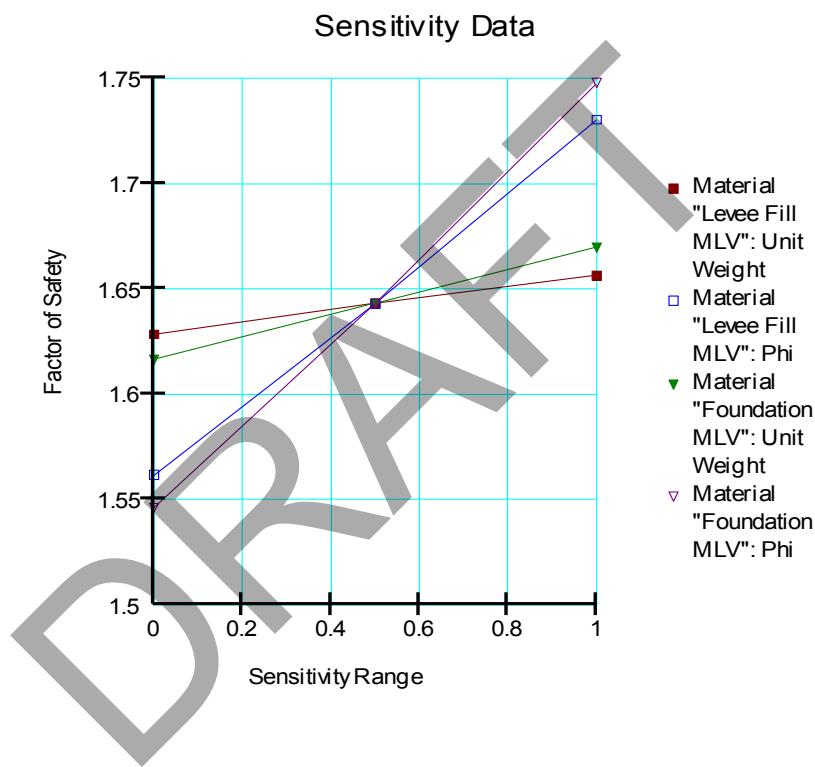
Project	Puyallup General Investigation
Feature	Water Ski
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Water Ski cross section from STA 43+87. Water Surface Elevation is at the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	35	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-3.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	34	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0	1.64	
2	1	-3.3	120	35	1.5	-3.3	120	34	0	0	1.68	
3	2	-3.3	120	35	1.5	-3.3	120	34	0	0	1.66	-0.02
4	1.5	-4.3	120	35	1.5	-3.3	120	34	0	0	1.84	
5	1.5	-2.3	120	35	1.5	-3.3	120	34	0	0	1.46	-0.38
6	1.5	-3.3	115	35	1.5	-3.3	120	34	0	0	1.63	
7	1.5	-3.3	125	35	1.5	-3.3	120	34	0	0	1.66	0.02784
8	1.5	-3.3	120	32	1.5	-3.3	120	34	0	0	1.56	
9	1.5	-3.3	120	38	1.5	-3.3	120	34	0	0	1.73	0.16868
10	1.5	-3.3	120	35	1	-3.3	120	34	0	0	1.70	
11	1.5	-3.3	120	35	2	-3.3	120	34	0	0	1.62	-0.08
12	1.5	-3.3	120	35	1.5	-4.3	120	34	0	0	1.46	
13	1.5	-3.3	120	35	1.5	-2.3	120	34	0	0	1.82	0.36
14	1.5	-3.3	120	35	1.5	-3.3	115	34	0	0	1.62	
15	1.5	-3.3	120	35	1.5	-3.3	125	34	0	0	1.67	0.05316
16	1.5	-3.3	120	35	1.5	-3.3	120	31	0	0	1.55	
17	1.5	-3.3	120	35	1.5	-3.3	120	37	0	0	1.75	0.20133
18	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		
19	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		0
20	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		
21	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		0

Standard deviation of F,	$\sigma_F$	0.297
Coefficient of variation of F,	$V_F$	0.181
Log normal reliability index,	$\beta_{LN}$	2.677
Reliability		0.996
Probability of failure		0.004

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.6285027	1.5617751	1.6164235	1.5463949
0.5	1.6430205	1.6430205	1.6430205	1.6430205
1	1.6563405	1.7304522	1.6695815	1.7477221

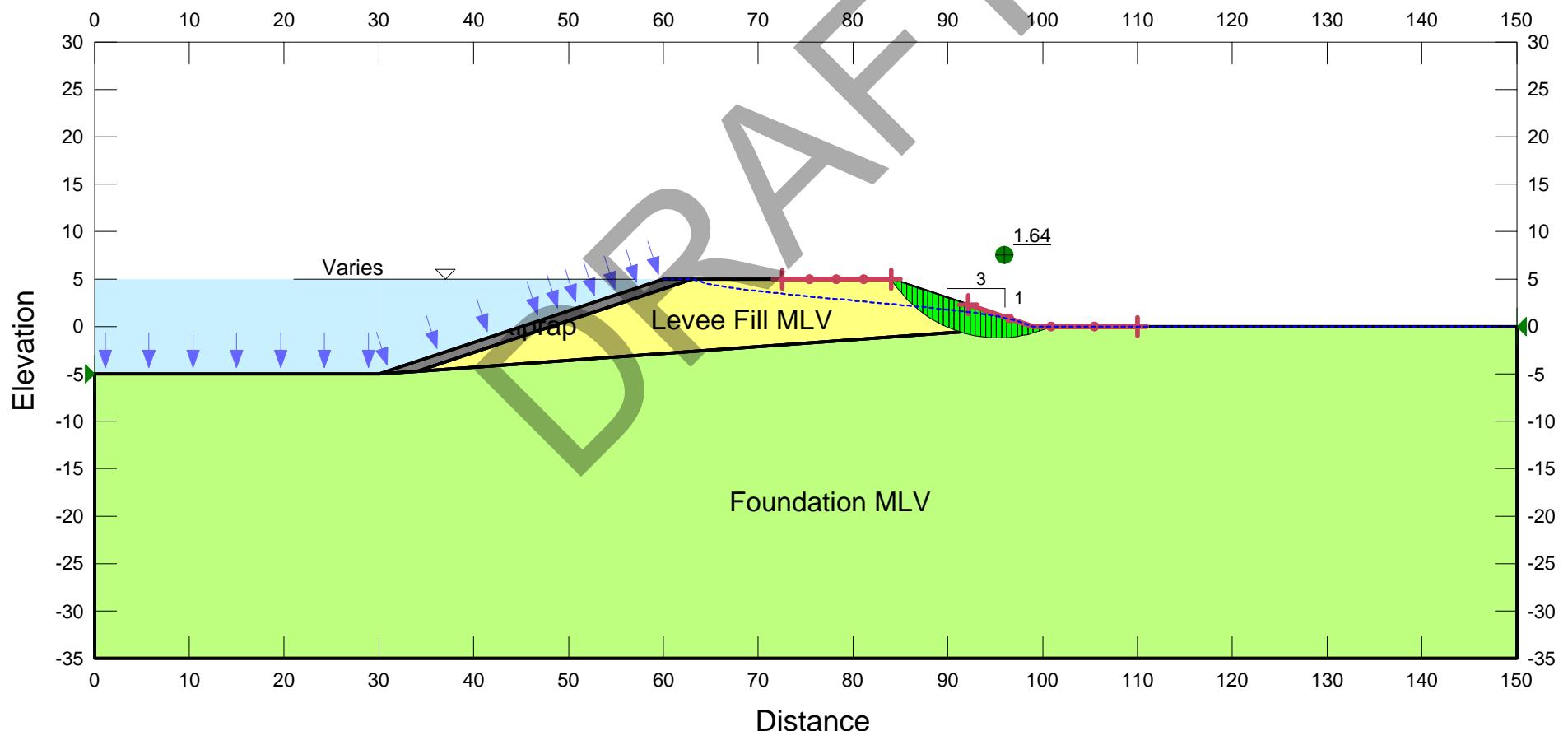


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

**Riprap**  
log(K-Sat): 0 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 115 pcf  
Phi: 45 degs

**Levee Foundation (SP-SM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Water Ski
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Water Ski Levee cross section from STA 43+87. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3.3	cm/s	1
5	$\log(K_h)$ (Foundation)	-3.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	8.24	
2	52.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	7.53	
3	62.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	8.96	1.43086
4	57.6	1	1.5	-3.3	-3.3	0	0	0	0	0	8.10	
5	57.6	2	1.5	-3.3	-3.3	0	0	0	0	0	8.35	0.24181
6	57.6	1.5	1	-3.3	-3.3	0	0	0	0	0	9.56	
7	57.6	1.5	2	-3.3	-3.3	0	0	0	0	0	7.40	-2.16021
8	57.6	1.5	1.5	-4.3	-3.3	0	0	0	0	0	10.80	
9	57.6	1.5	1.5	-2.3	-3.3	0	0	0	0	0	6.25	-4.55413
10	57.6	1.5	1.5	-3.3	-4.3	0	0	0	0	0	6.21	
11	57.6	1.5	1.5	-3.3	-2.3	0	0	0	0	0	10.86	4.64791
12	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		

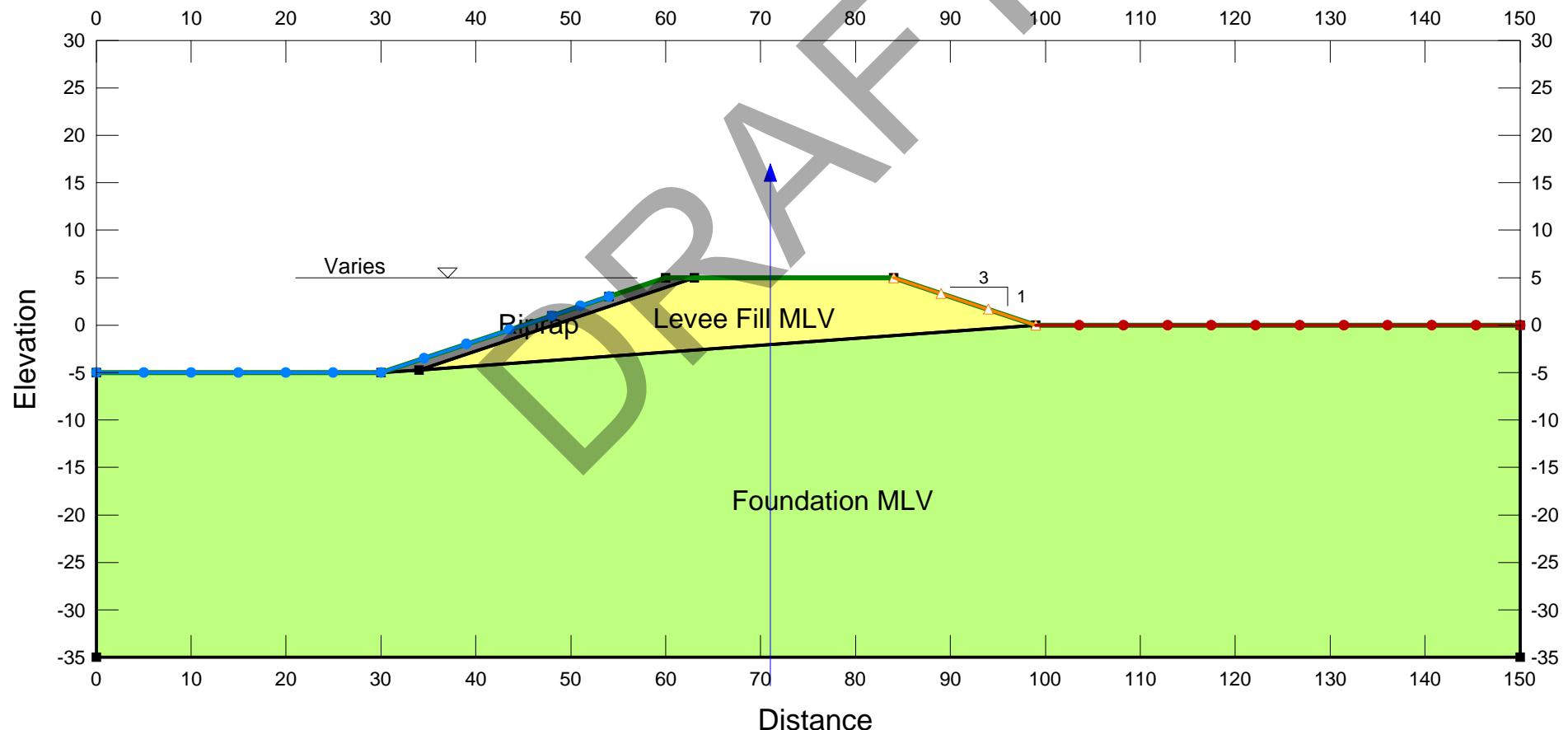
Standard deviation of F,	$\sigma_F$	3.504
Coefficient of variation of F,	$V_F$	0.425
Log normal reliability index,	$\beta_{LN}$	4.970
Reliability		1.000
Probability of failure		3.3E-07

**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

**Riprap**  
log(K-Sat): 0 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 115 pcf  
Phi: 45 degs

**Levee Foundation (SP-SM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

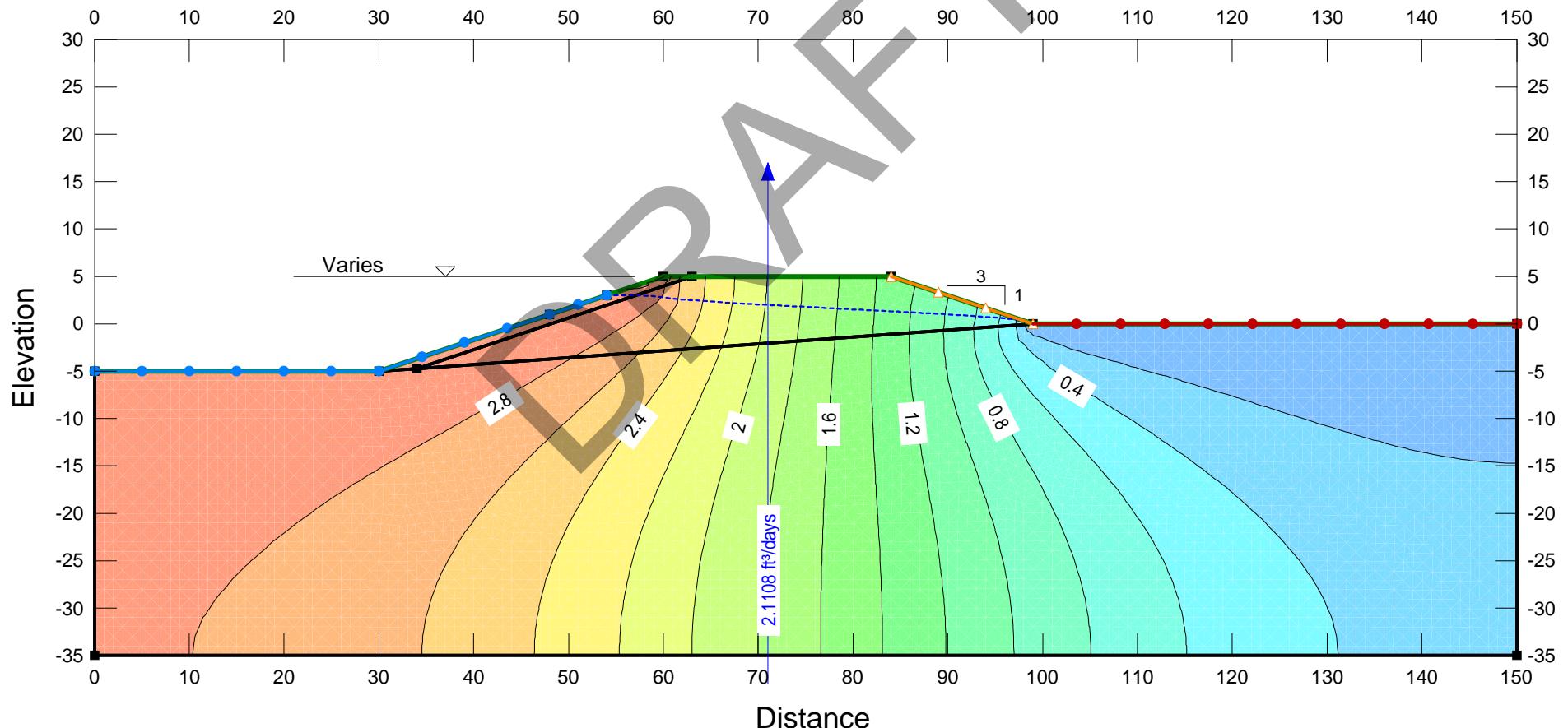


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

**Riprap**  
 $\log(K\text{-Sat})$ : 0 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
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**Levee Foundation (SP-SM)**  
 $\log(K\text{-Sat})$ : -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

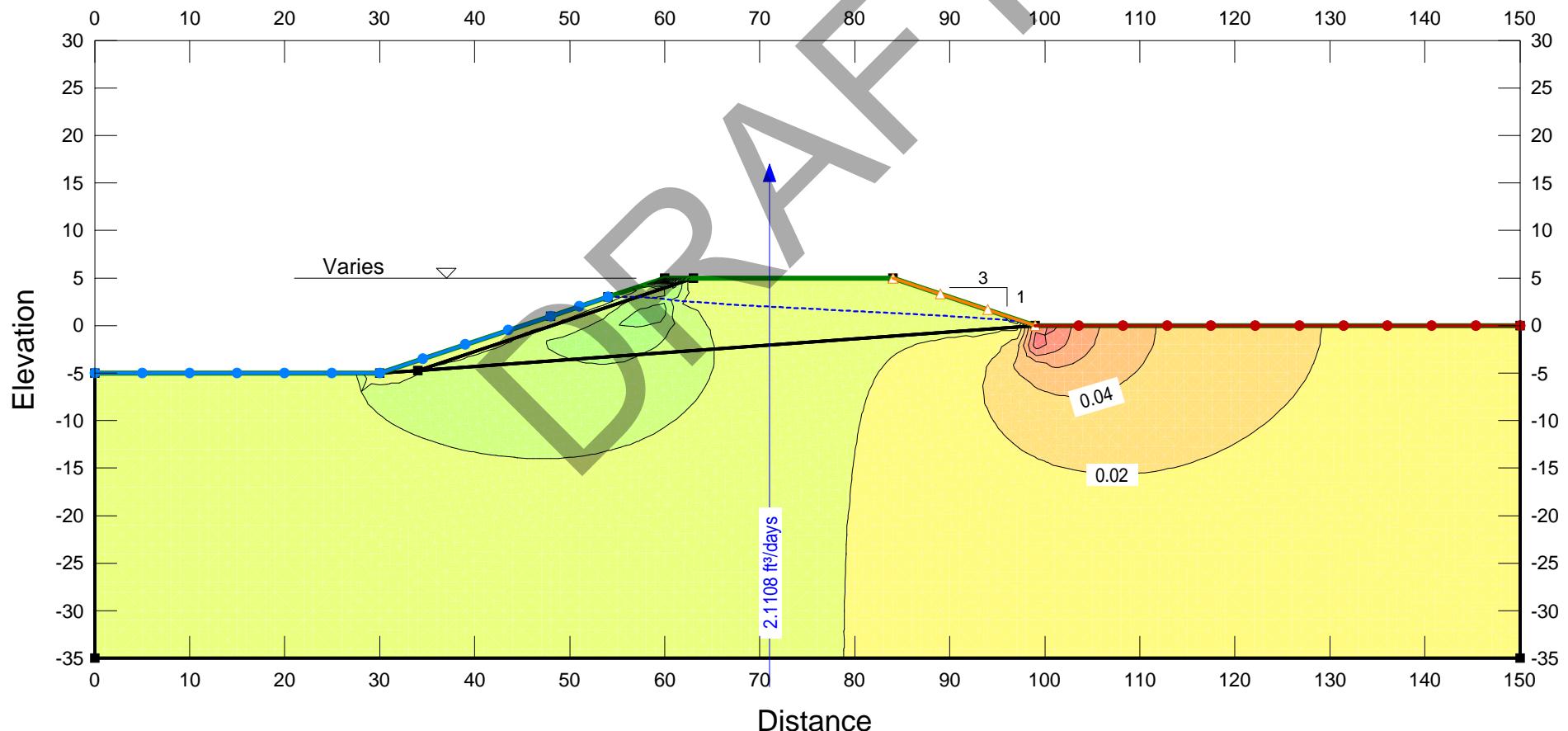


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
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 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)



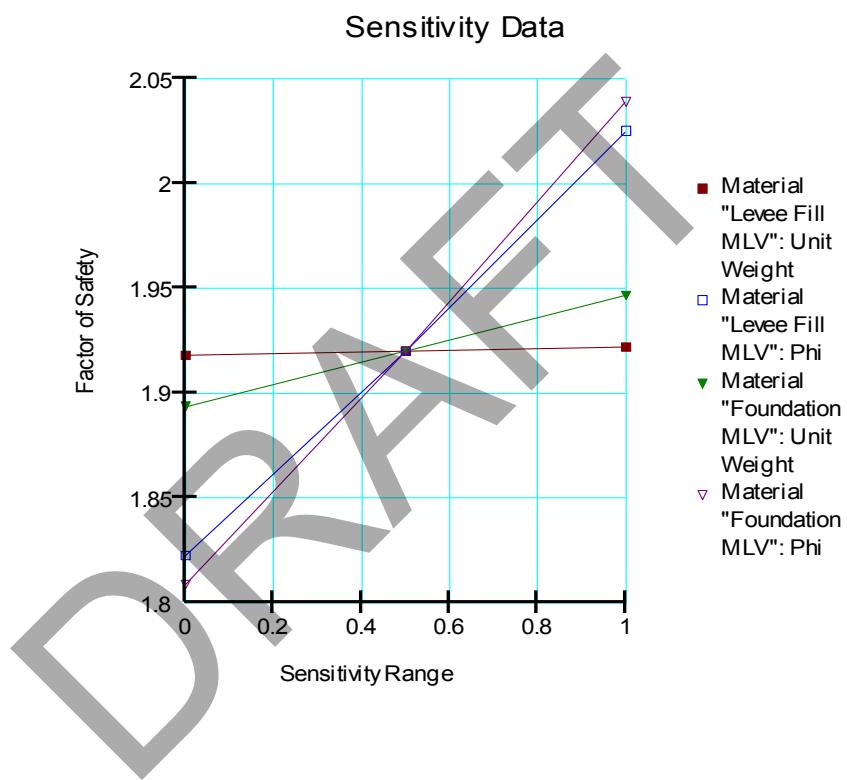
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Water Ski
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Water Ski Levee cross section from STA 43+87. Water Surface Elevation is 2 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	35	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-3.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	34	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0	1.92	
2	1	-3.3	120	35	1.5	-3.3	120	34	0	0	1.95	
3	2	-3.3	120	35	1.5	-3.3	120	34	0	0	1.94	-0.01
4	1.5	-4.3	120	35	1.5	-3.3	120	34	0	0	2.01	
5	1.5	-2.3	120	35	1.5	-3.3	120	34	0	0	1.77	-0.24
6	1.5	-3.3	115	35	1.5	-3.3	120	34	0	0	1.92	
7	1.5	-3.3	125	35	1.5	-3.3	120	34	0	0	1.92	0.00404
8	1.5	-3.3	120	32	1.5	-3.3	120	34	0	0	1.82	
9	1.5	-3.3	120	38	1.5	-3.3	120	34	0	0	2.03	0.20245
10	1.5	-3.3	120	35	1	-3.3	120	34	0	0	1.94	
11	1.5	-3.3	120	35	2	-3.3	120	34	0	0	1.90	-0.04
12	1.5	-3.3	120	35	1.5	-4.3	120	34	0	0	1.77	
13	1.5	-3.3	120	35	1.5	-2.3	120	34	0	0	2.00	0.23
14	1.5	-3.3	120	35	1.5	-3.3	115	34	0	0	1.89	
15	1.5	-3.3	120	35	1.5	-3.3	125	34	0	0	1.95	0.05297
16	1.5	-3.3	120	35	1.5	-3.3	120	31	0	0	1.81	
17	1.5	-3.3	120	35	1.5	-3.3	120	37	0	0	2.04	0.23001
18	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		
19	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		0
20	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		
21	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		0

Standard deviation of F,	$\sigma_F$	0.229
Coefficient of variation of F,	$V_F$	0.119
Log normal reliability index,	$\beta_{LN}$	5.442
Reliability		1.000
Probability of failure		2.6E-08

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	1.9181072	1.8227095	1.8937293	1.8089767
0.5	1.9202149	1.9202149	1.9202149	1.9202149
1	1.9221449	2.0251583	1.9466997	2.0389902

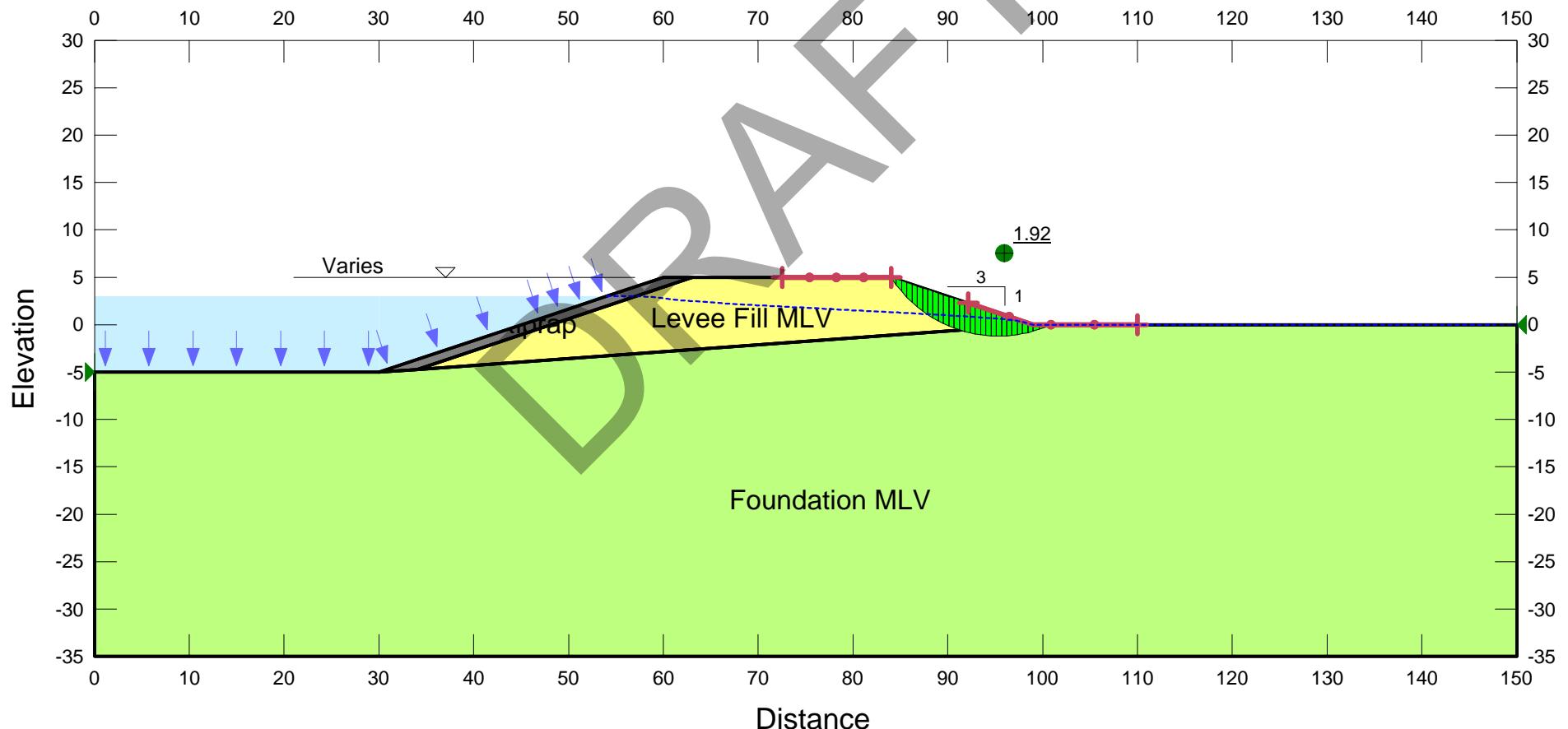


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

**Riprap**  
log(K-Sat): 0 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 115 pcf  
Phi: 45 degs

**Levee Foundation (SP-SM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)



**Taylor's series method spreadsheet**

Project	Puyallup General Investigation
Feature	Water Ski
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Underseepage uplift / erosion & piping
Method of computing	
Factor of safety (F)	F = buoyant unit wt / (exit gradient * unit wt water)
Notes:	Water Ski Levee cross section from STA 43+87. Water Surface Elevation is 4 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	$\gamma_{buoyant}$	57.6	pcf	5
2	$(K_h/K_v)$ (Fill)	1.5	unitless	0.5
3	$(K_h/K_v)$ (Foundation)	1.5	unitless	0.5
4	$\log(K_h)$ (Fill)	-3.3	cm/s	1
5	$\log(K_h)$ (Foundation)	-3.3	cm/s	1
6				
7				
8				
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	24.95	
2	52.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	22.78	
3	62.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0	27.11	4.33125
4	57.6	1	1.5	-3.3	-3.3	0	0	0	0	0	23.08	
5	57.6	2	1.5	-3.3	-3.3	0	0	0	0	0	23.08	0
6	57.6	1.5	1	-3.3	-3.3	0	0	0	0	0	23.08	
7	57.6	1.5	2	-3.3	-3.3	0	0	0	0	0	23.08	0
8	57.6	1.5	1.5	-4.3	-3.3	0	0	0	0	0	9.36	
9	57.6	1.5	1.5	-2.3	-3.3	0	0	0	0	0	20.51	11.151
10	57.6	1.5	1.5	-3.3	-4.3	0	0	0	0	0	18.46	
11	57.6	1.5	1.5	-3.3	-2.3	0	0	0	0	0	14.89	-3.5732
12	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
13	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
14	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
15	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
16	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
17	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
18	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
19	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
20	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		
21	57.6	1.5	1.5	-3.3	-3.3	0	0	0	0	0		

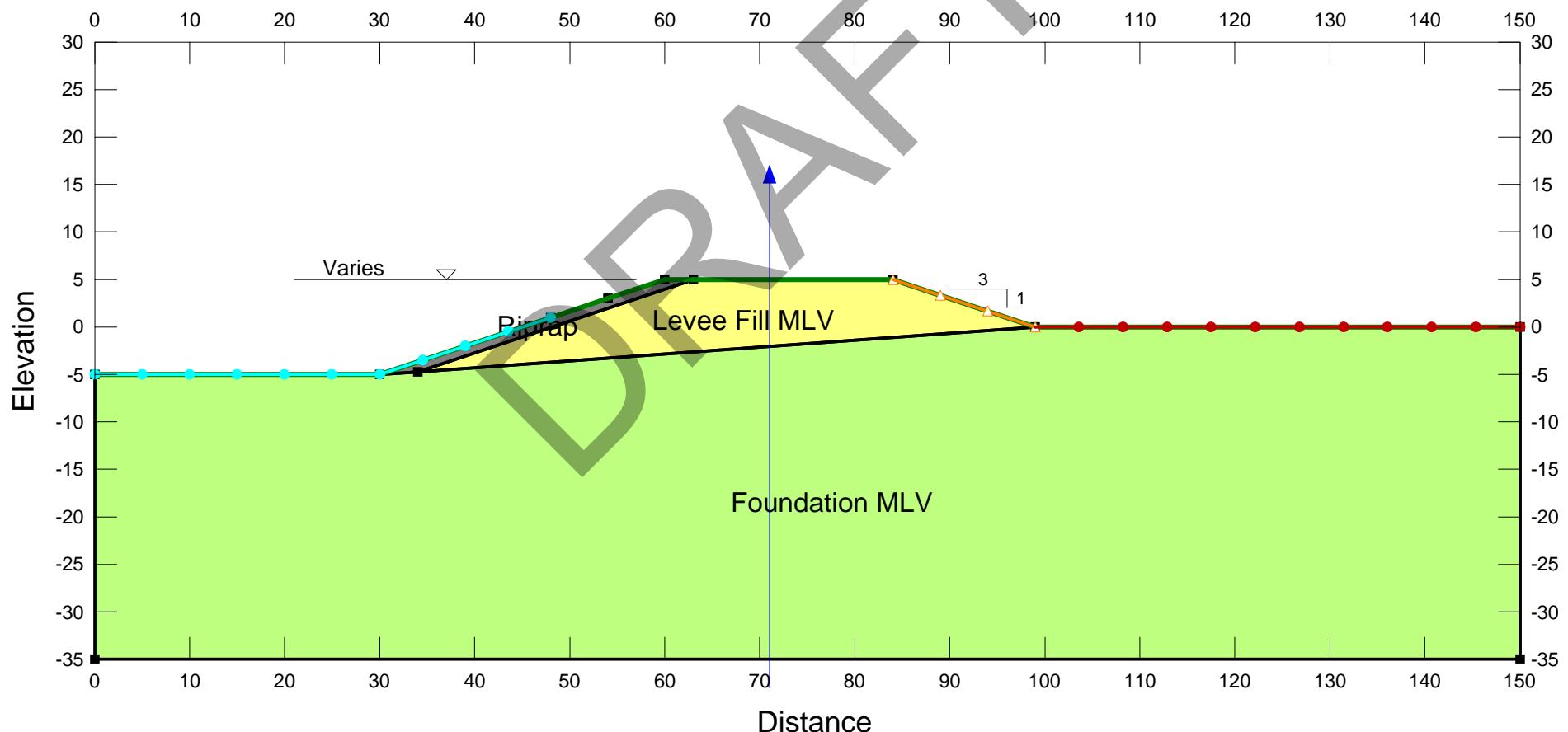
Standard deviation of F,	$\sigma_F$	6.242
Coefficient of variation of F,	$V_F$	0.250
Log normal reliability index,	$\beta_{LN}$	12.930
Reliability		1.000
Probability of failure		0.0E+00

**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
 KH/KV Ratio: 1.5  
 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SP-SM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

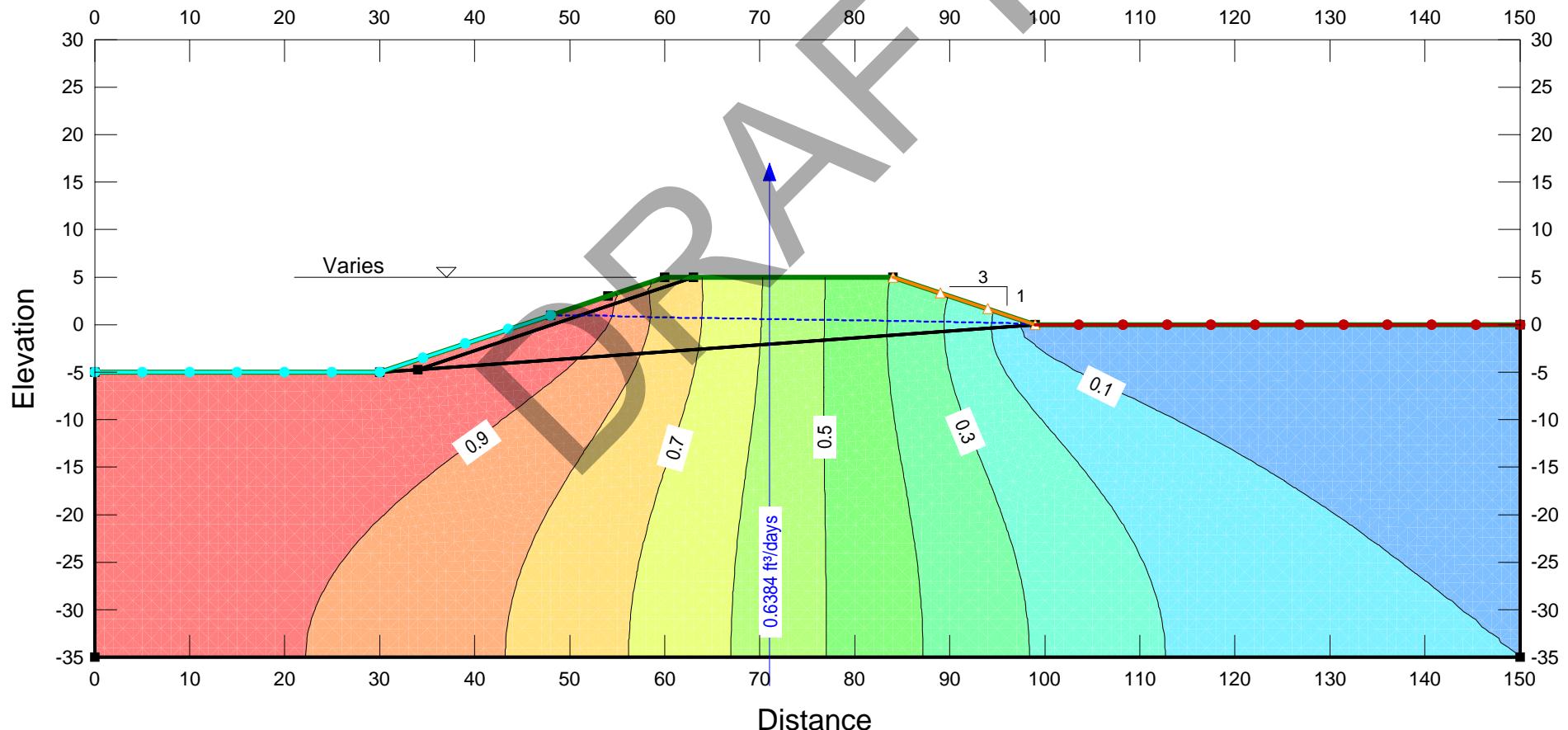


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
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**Riprap**  
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**Levee Foundation (SP-SM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)

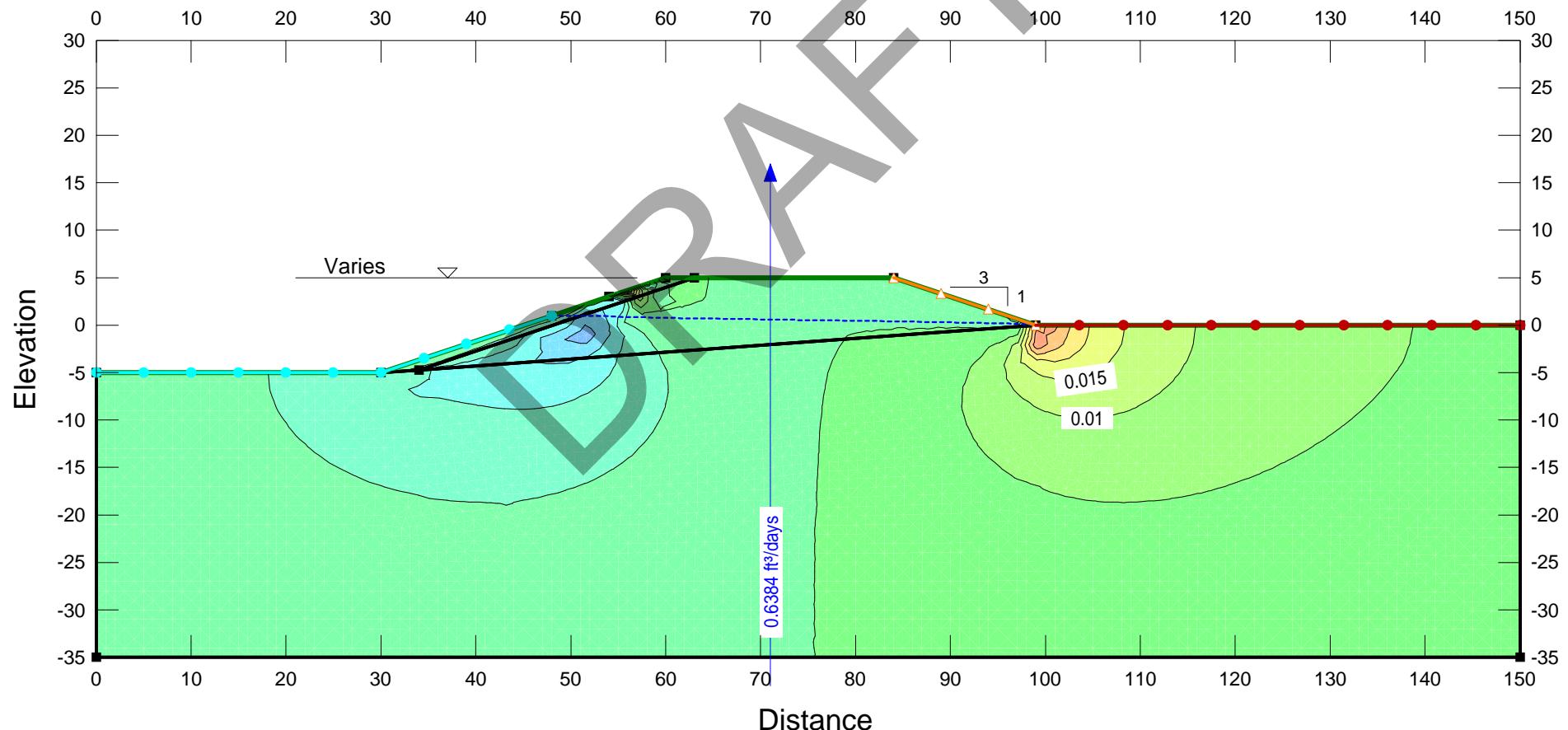


**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 35 degs (+/- 3)

**Riprap**  
 log(K-Sat): 0 cm/s  
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 Unit Weight: 115 pcf  
 Phi: 45 degs

**Levee Foundation (SP-SM)**  
 log(K-Sat): -3.3 cm/s (+/- 1)  
 KH/KV Ratio: 1.5 (+/- 0.5)  
 Unit Weight: 120 pcf (+/- 5)  
 Phi: 34 degs (+/- 3)



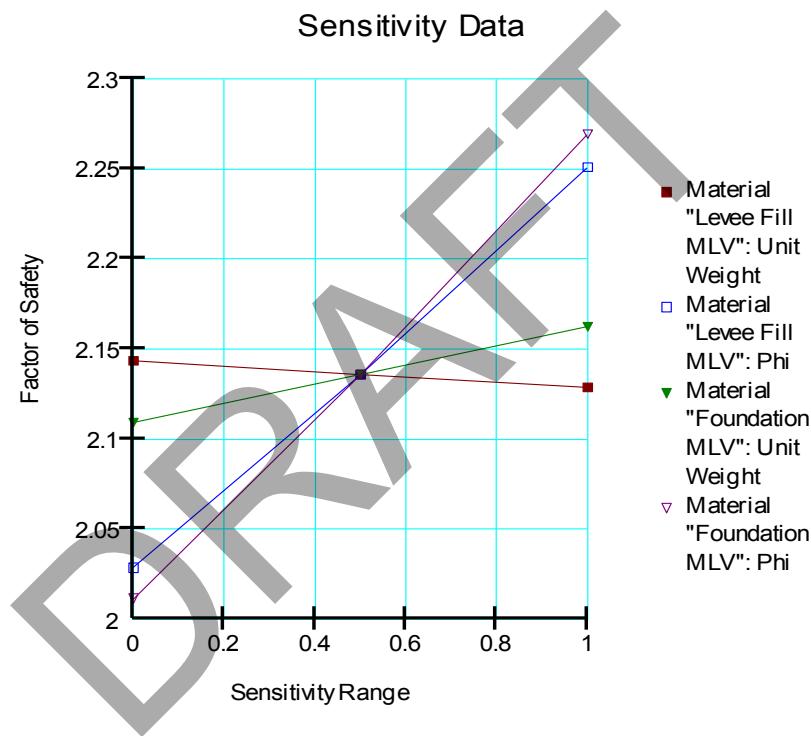
Taylor's series method spreadsheet	
Project	Puyallup General Investigation
Feature	Water Ski
Date	5-Nov-11
Computed by	Michael Gonia
Potential failure mode	Slope Stability
Method of computing	
Factor of safety (F)	F = Shear Strength/Shear Strength Required
Notes:	Water Ski Levee cross section from STA 43+87. Water Surface Elevation is 4 feet below the top of levee.

Variables				
Number	Description	Most Likely Value	Units	Standard deviation
1	( $K_h/K_v$ ) (Fill)	1.5	unitless	0.5
2	$\log(K_h)$ (Fill)	-3.3	cm/s	1
3	$\gamma_{sat}$ (Fill)	120	pcf	5
4	$\phi'$ (Fill)	35	degrees	3
5	( $K_h/K_v$ ) (Foundation)	1.5	unitless	0.5
6	$\log(K_h)$ (Foundation)	-3.3	cm/s	1
7	$\gamma_{sat}$ (Foundation)	120	pcf	5
8	$\phi'$ (Foundation)	34	degrees	3
9				
10				

Computation number	Variable values										F	$\Delta F$
	1	2	3	4	5	6	7	8	9	10		
1	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0	2.14	
2	1	-3.3	120	35	1.5	-3.3	120	34	0	0	2.16	
3	2	-3.3	120	35	1.5	-3.3	120	34	0	0	2.15	-0.01
4	1.5	-4.3	120	35	1.5	-3.3	120	34	0	0	2.16	
5	1.5	-2.3	120	35	1.5	-3.3	120	34	0	0	2.09	-0.07
6	1.5	-3.3	115	35	1.5	-3.3	120	34	0	0	2.14	
7	1.5	-3.3	125	35	1.5	-3.3	120	34	0	0	2.13	-0.01453
8	1.5	-3.3	120	32	1.5	-3.3	120	34	0	0	2.03	
9	1.5	-3.3	120	38	1.5	-3.3	120	34	0	0	2.25	0.2224
10	1.5	-3.3	120	35	1	-3.3	120	34	0	0	2.14	
11	1.5	-3.3	120	35	2	-3.3	120	34	0	0	2.13	-0.01
12	1.5	-3.3	120	35	1.5	-4.3	120	34	0	0	2.09	
13	1.5	-3.3	120	35	1.5	-2.3	120	34	0	0	2.16	0.07
14	1.5	-3.3	120	35	1.5	-3.3	115	34	0	0	2.11	
15	1.5	-3.3	120	35	1.5	-3.3	125	34	0	0	2.16	0.05292
16	1.5	-3.3	120	35	1.5	-3.3	120	31	0	0	2.01	
17	1.5	-3.3	120	35	1.5	-3.3	120	37	0	0	2.27	0.25803
18	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		
19	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		0
20	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		
21	1.5	-3.3	120	35	1.5	-3.3	120	34	0	0		0

Standard deviation of F,	$\sigma_F$	0.180
Coefficient of variation of F,	$V_F$	0.084
Log normal reliability index,	$\beta_{LN}$	8.998
Reliability		1.000
Probability of failure		0.0E+00

Sensitivity Range	Material "Levee Fill MLV": Unit Weight Factor of Safety	Material "Levee Fill MLV": Phi Factor of Safety	Material "Foundation MLV": Unit Weight Factor of Safety	Material "Foundation MLV": Phi Factor of Safety
0	2.1434666	2.0287613	2.1094395	2.0114532
0.5	2.1358897	2.1358897	2.1358897	2.1358897
1	2.1289342	2.2511638	2.1623594	2.2694845



**Water Ski Levee**  
**Carbon River**  
**STA 43+87**

**Levee Fill (GM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 35 degs (+/- 3)

**Riprap**  
log(K-Sat): 0 cm/s  
KH/KV Ratio: 1.5  
Unit Weight: 115 pcf  
Phi: 45 degs

**Levee Foundation (SP-SM)**  
log(K-Sat): -3.3 cm/s (+/- 1)  
KH/KV Ratio: 1.5 (+/- 0.5)  
Unit Weight: 120 pcf (+/- 5)  
Phi: 34 degs (+/- 3)

